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EDITED BY J. MCKEEN CATTELL

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THE SCIENTIFIC MONTHLY

MARCH, 1936

THE PLANT LIFE OF THE SONORAN DESERT

By Dr. FORREST SHREVE

DESERT LABORATORY OF THE CARNEGIE INSTITUTION OF WASHINGTON

For thousands of years the human race has shown a strong liking for the desert. Important steps in our early civilization were made by the people of the arid lands of southwestern Asia. For many centuries the nations that were dominant in human progress held sway over territory that is mainly desert or semi-desert. In Arabia and around the edges of the Sahara can still be found people living under adjustments to desert conditions that were made over four thousand years ago. Before the seventh century of the Christian era no important cultures developed in the wooded and rainy parts of the Old World. When America was discovered, its highest civilizations were found not in the Mississippi Valley or the Valley of the Amazon but in the arid plateaus of Mexico and Peru. Early men seem to have preferred to live in the open country wherever living was possible.

Desert Limitations

The life of primitive desert people is led in a state of precise adjustment to their uncongenial and immutable environment. The advances which they are able to make are closely controlled by these adjustments. They are vitally dependent on water supply, arable soil or forage for their animals. Under such conditions environment controls the distribution and abundance of man as sharply as it does of plants.

The events which led the political dominance of the world out of the Mediterranean region into cooler and moister western Europe at the same time liberated the march of our material advancement from the limitations that the meager resources of the desert had placed upon it. It is very certain that if the course of our civilization had been run solely in the desert regions in which it began we would be very far behind our present stage of advancement.

The thorough exploration of the world, the settlement of new lands and the rapid growth of population have again brought us to the edge of the desert, not looking out at more promising lands but looking in and appraising it as a place to live. It is one of the last unoccupied lands, one of the last outlets for the growing masses of humanity.

Civilized man has already begun to go back into the desert. In South Africa and Australia the frontiers have been gradually pushed out into regions once regarded as uninhabitable. In the United States for the last thirty years there has been a slackening in the growth of population in some of the northeastern states and a steady growth in those states which have little rain and much sunshine.

The desert settler of to-day has countless advantages over the ancients and innumerable contrivances that help in the adjustment of his more exacting life to

the same group of inexorable conditions that will always be the desert. To what extent will the settler be able to utilize the desert? What factors will limit his activities? How permanent wiil his efforts be? Can his life in the desert be made rich, full and happy or will it be meager, anxious and bare? There are many uncertainties involved in the answers to these questions, but we may be very sure that whatever success he achieves will depend chiefly upon his knowledge of the desert. To this the scientific man can hope to make many valuable contributions.

Concept of Desert

Desert is not a simple concept in any of its physical or biological aspects. Examples of it range from the nearly barren sands of the Sahara and the Gobi, through the alkaline plains of Nevada and the Kalahari to the relatively green slopes of Tehuacan or the Karroo. Rainfall, temperature, amount of cloudiness and wind are all unlike from desert to desert. Geological structure, physiographic development and mineralogical and soil character all add further variety to the scattered desert and semi-desert regions which form one fifth of the land surface of the earth.

An adequate definition of desert must be based on a group of characteristics rather than a single one. Deficient and uncertain rainfall is the basic feature, but it may vary from almost nothing to more than twenty inches. It is only in tropical latitudes that the latter amount is found, supporting there a vegetation much like that which grows with ten inches of rain in temperate latitudes. The biologist regards as desert all those areas in which deficient rainfall and all its consequences have made a strong impression on the structure, functions and behavior of living things. The Standard Dictionary defines desert as a place where irrigation is essential to permanent occupation. This, of course, is merely an expression of the principal consequence of desert conditions from a homocentric view-point.

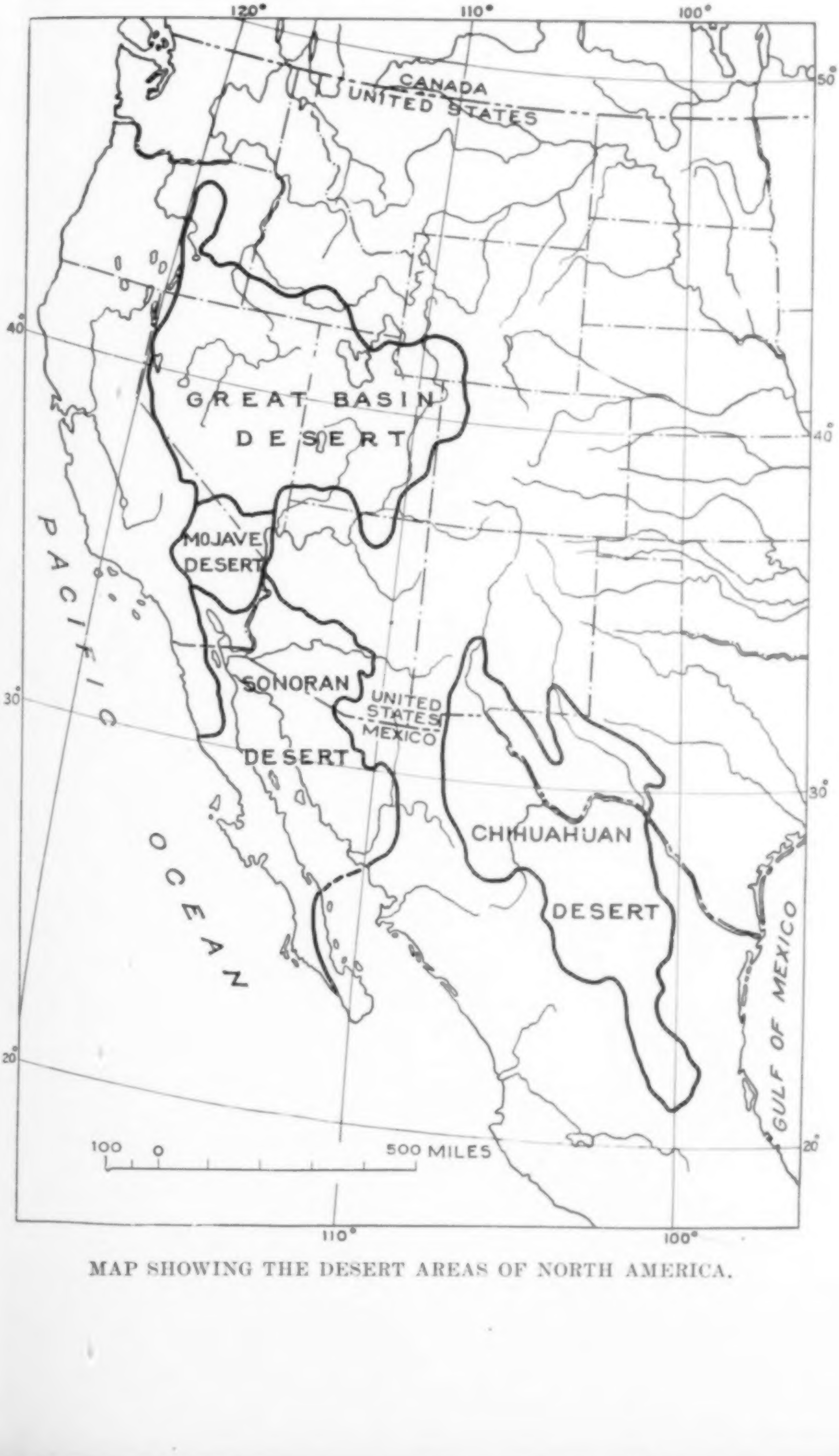
Deserts of the World

A glance at a map of the world on which the large desert areas are shown reveals their extent, their position just outside the tropical zone and their isolation from each other. The largest and most arid area is the one which extends from the Atlantic coast of Africa through Egypt and Asia Minor eastward nearly across Asia. Large arid and semi-arid areas exist in South Africa, and the major part of Australia is desert. In the western hemisphere there are deserts in both North and South America, much smaller than those of the eastern hemisphere but exhibiting an equally wide range from extreme aridity to semi-arid areas or transitions to grassland or thorn-forest.

In each of the six large deserts the plant life is distinct from that of the surrounding regions and distinct from that of the other deserts. There is a slight relationship between South Africa and Australia and also between North and South America. At the same time that the species of plants in the deserts are distinct, it has been found that the majority belong to genera found elsewhere and nearly all of them to families which are either richly or poorly represented outside the desert. The lack of strong relationship between the plants of the six great deserts indicates that their isolation from one another has given each of them a separate history. Also, the generic and family relationships of the plants to those of moister places demonstrates that each of the deserts has derived its plants from adjacent regions of more favorable climate.

Effect of Desert on Plants

Great interest attaches to the genera and especially the families of plants which are confined, or even nearly con-



MAP SHOWING THE DESERT AREAS OF NORTH AMERICA.

fined, to the desert. They are the living representatives of the races of plants which have undergone the greatest change in entering the desert and in acquiring all the characteristics that have made possible their survival and success. We see that the evolutionary development which has accompanied entry into regions of aridity and brilliant sunshine has in many cases been so far-reaching as to effect the flower, fruit, seed, woody tissues and other features on which our conceptions of plant relationship are based. In a far greater number of cases the plants which have entered the desert have only undergone modification of the root, stem, leaf and other vegetative structures. Some of these changes have been so profound as to make the appearance of the plant wholly unlike that of its nearest relatives of the savanna or forest, yet the flowers and fruit are almost unchanged.

In any effort to understand the development of the plants of the desert it is important to learn as much as possible about their origin and the history of their descent, and also to know fully their structure, physiological behavior, life history from seed to adult and relationships to climate and soil. It must be kept in mind that the plant is both a genetic entity and a physiological entity, that it is both a descendant and an independent individual. Characters inherited from ancestors of high moisture requirement have been reduced and transformed by the evolutionary processes which have accompanied the settlement of the desert by plants. We have before us for study both the history of these processes and their end results in the plants of to-day. The history must be compiled from bits of evidence of every pertinent kind. The end results are to be found by investigation of the plants which have stood the test of adjusting themselves to new conditions or to new localities in which the same conditions have long persisted.

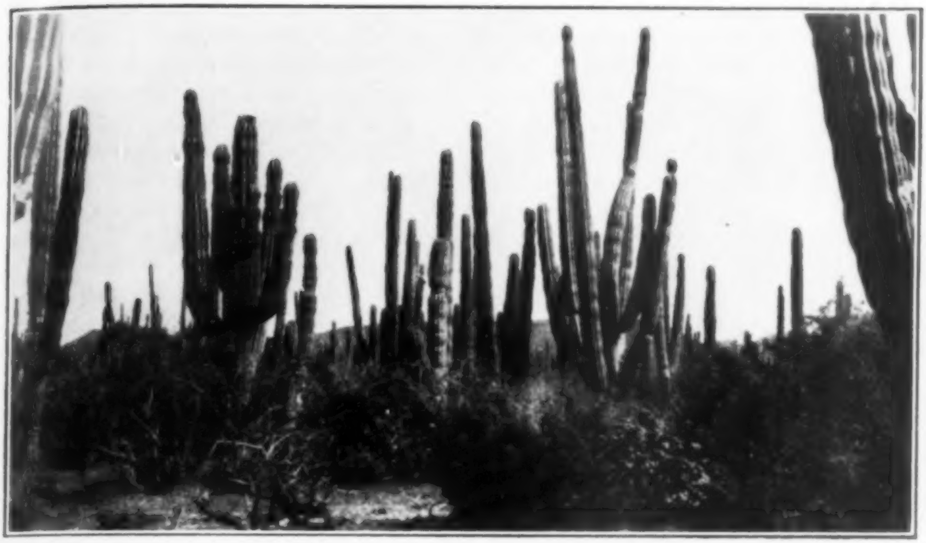
American Deserts

For over thirty years work on desert plants and the conditions which they encounter has been conducted by the Carnegie Institution at the Desert Laboratory, located near Tucson, Arizona. There have been two or three resident investigators at the laboratory throughout its operation, and numerous visiting investigators have worked there from time to time for short periods. The work of the laboratory has done much to increase our knowledge of the desert and of the plant life of the surrounding region.

The desert region of North America extends from eastern Oregon to the Mexican state of Puebla and from the Pacific coast of Baja California to the valley of Devil's River in Texas. It is separated into two parts by the high plains along the continental divide and by the Sierra Madre of northwestern Mexico. The Chihuahuan Desert, forming the eastern part, is poorly known from the botanical standpoint. The western part falls rather naturally into three areas, which differ in altitude, physiographic features and climate, as well as in plant and animal life. These areas are the Great Basin, the Mojave Desert and the Sonoran Desert. All four of the subdivisions of the North American Desert have received some attention at the hands of investigators at the Desert Laboratory. The work has been chiefly, however, in southern Arizona, extending in recent years to the entire Sonoran Desert.

Types of Desert Plants

We have seen that in America, as well as in the Old World, the desert is characterized by distinct species and by plants of unusual structure and behavior. Also, there are certain features in the make-up of the natural communities of plants which do much to lend character to the desert landscape. The most casual observer will note that desert



THE MASSIVE *PACHYCEREUS PRINGLEI*

REACHES ITS MAXIMUM DENSITY AT THE HEAD OF CONCEPCION BAY, BAJA CALIFORNIA.

plants are widely spaced, often leaving much bare ground, and that their height is less than that of hardwood or coniferous forest trees. Both of these features are to be explained by the scanty water supply. Another commonly observed feature of desert vegetation is the mingling of plants which differ greatly in size, form, manner of branching and method of exposing their green surfaces. This heterogeneity is much more in evidence in the Sonoran and Chihuahuan Deserts than it is in the Mojave or the Great Basin. It is, in fact, a feature of the warmer deserts and does much to augment their biological interest. Where such heterogeneity exists it is an indication of the numerous ways in which evolutionary development has worked out solutions for the problem of life in the desert.

An analysis of these solutions reveals three main classes, represented by the short-lived or ephemeral plants, the succulent and the non-succulent ones. The ephemerals are scarcely desert plants in their anatomy or physiology, since they appear only in the rainy seasons and wholly escape the difficulties of the critical months of the year. In one important respect they show remarkable fitness for their place in nature. With the sudden arrival of favorable conditions—a moist soil of the proper temperature—their seeds germinate promptly and they grow with astonishing speed. In many species only five weeks elapse from germination to the maturing of a new crop of seeds. The duration of the rainy period determines whether such a plant reaches a height of one inch and produces one flower or whether it grows to eighteen or twenty inches and matures a thousand seeds.

The succulent group is mainly represented by the cacti in America and by the Euphorbias in South Africa. In the other large deserts the succulent is a very rare type, although in North Africa and Australia the cactus has been introduced from America and has flourished. In these plants the leaf has been dispensed with and its work has been taken over by the green tissue which clothes the

stem. Also, the stem has undergone enlargement through the development of great masses of tissue in which an accumulation of water is held. The root system of the cactus is widely distributed near the surface of the ground. When rain wets the uppermost layers of soil the plant quickly renews its water content, perhaps badly depleted by many rainless months.

The non-succulent perennial plants are active throughout the year or else throughout the frostless season. Their water supply must be renewed daily and survival depends on a deep root system, widely distributed through the lower levels of the soil, in which a modicum of moisture persists throughout the year.

In brief, the ephemeral plants escape the rigors of a dry climate, the succulents have a mechanism which equalizes the irregularity of water supply, and the non-succulents have the daily problem of maintaining equality between their water loss and water supply. Each of these three types of adjustment to desert conditions is found in hundreds of species, and the three types grow side by side in the vegetation.

In a closer study of the great array of forms found in the warmer and less extreme deserts the three main types of plants that have been mentioned may be subdivided many times.

Ephemeral Plants

Although the ephemeral plants do not show any outstanding features of structure they have nevertheless many minor peculiarities of habit, branching and leaf anatomy which appear to be of importance in their brief lives and to aid them in making the maximum use of the last residue of moisture in a rapidly drying soil. There are great differences in the relative abundance of the numerous species from year to year, which has been found to depend upon whether the rains come early or late, in a few heavy storms or many light ones, and whether there is much or little cloudiness. Their relative size and abundance over a given area furnish an accurate index of the amount of moisture in the soil and of the conditions for evaporation. The slightly shaded area around every bush or tree is more heavily carpeted with ephemerals than is the open ground nearby. In just such spots, too, the seedlings of the large perennials usually make their start.

The eastern half of the Sonoran Desert is almost unique among the deserts of the world in having two well-defined rainy seasons, one in mid-summer and one in late winter. In each of these seasons there appears a wholly different group of ephemerals. Never by any chance does a summer species appear in the winter or *vice versa*. In the warm moist soil of summer lie the seeds of the winter ephemerals as dormant as if they were in a dry refrigerator. This behavior is due solely to a difference in the temperature required for germination of the summer and winter plants. It is an easy matter to secure seedlings of winter ephemerals in summer by appropriate cooling of the soil.

In order to understand the presence of the two sets of ephemerals it is necessary to investigate the geographic distribution of the members of both groups and their seasonal behavior in other regions. There are no species in the winter group which are found only in the area of biseasonal rainfall. All of them are found also in the deserts of California, which have rain only in winter. In fact, the winter ephemerals of Arizona are only a small group of wanderers from the large number found in the Californian deserts. The summer ephemerals, on the other hand, are of southern range, extending into Arizona from Sonora and from the thorn-forest of Sinaloa, where the summer rains are heavier than the winter ones. Here, again, the number of summer species in Arizona is only a fraction of the number found in southern Sonora.

Among the winter ephemerals is a small carrot (*Daucus pusillus*), which ranges from South Carolina to California. In the east it is a summer plant, in the west a winter one. In southern Sonora and in southern Baja California several of the summer plants of the Tucson region have been found growing in the winter rainy period. These cases show that a suitable soil temperature for germination has been a fundamental condition in determining the geographic spread of the ephemerals. In southern Sonora the soil in winter is as warm locally as it is in Arizona in summer, and there is nothing to prevent a summer ephemeral from appearing in both seasons. Such cases are excellent examples of the manner in which organisms spread long distances with little or no modification by following lanes of migration in which they find the conditions to which they are accustomed, even if they be very local or very transitory. In this way the Tucson region has been invaded by a few of the winter ephemerals of California and a somewhat larger number of the summer ones of Sonora. The fact that biseasonal rainfall is a somewhat unusual climatic feature and that it is found over a relatively small area raises a question as to its age in geological terms and the influences exerted on it by minor fluctuations of climate. It seems highly probable that a fuller study of the ephemeral plants, their ranges and relationships, may throw some light on the recent climatic history of the Sonoran Desert.

Succulent Plants

Turning our attention again to the succulent plants we find them to be a richly developed group with a very important place in the vegetation of arid America. The very mention of desert brings to the minds of most travelers a picture of broad landscapes studded with prickly pears, bristling chollas and stately giant cacti. Only a few families have developed succulents in America and the cacti are by far the most important of them, with over 1,200 species. This great group originated somewhere

EXTENSIVE PLAINS

Along the Pacific coast in Baja California are dominated by the leaf-succulent *Agave goldmaniana.*

in tropical America and made its way from the forests through the semi-arid caatinga and thorn-forest into the deserts north and south of its center of origin.

The most primitive cactus is *Pereskia*, which has dark stems and rather fleshy leaves. It attains the size and form of a small tree, and there is nothing in its general appearance to suggest a close relationship to other cacti. The members of the genus are confined to the moist tropics of Mexico and Brazil. In *Pereskiopsis* we have another small genus of cacti, with true leaves but a fleshy green stem and a few weak spines. When the leaves fall from the older parts of the stem its appearance is much like that of some of the slender species of *Opuntia*. From these simple forms have arisen the great array of types now found in the cactus family, the novelty and grotesqueness of which have made them very popular in cultivation in the last ten years.

Several structural features have served to give the cacti their outstanding appearance, so unlike that of other plants. Most general have been the loss of the leaf as a permanent organ, the enlargement of the stem to accommodate water-storing tissue, and the development of localized spine-bearing structures known as "areoles." In several genera the stem is segmented into sections, which are flat and somewhat leaf-life; in others the stem is round, much branched and the surface occupied by close-set tubercles. In a large group, including massive erect forms as well as slender climbing ones, the stem is grooved or fluted and is thus able readily to accommodate its surface to great fluctuations in the water content of the tissues.

Still further variety is added to the vegetation of the American deserts by several groups of plants in which the leaves are succulent as well as the stems. The largest of the leaf succulents are the century plants, in which the stem is thick and succulent but so greatly shortened that the leaves arise very close together. Similar to the century plants but much smaller are the dudleyas, which are particularly abundant in Baja California.

It is very instructive to compare the Sonoran Desert with the Karroo Desert in South Africa with respect to the development of the succulent habit. In the latter there are no cacti, no century plants and no dudleyas, and yet there are plants closely resembling each of them. The similar conditions in these two widely separated deserts have brought about very similar types of plants, but they have little family relationship. In the Karroo the place of the cactus in the landscape is taken by members of the Euphorbia family, the place of the century plants is taken by the aloes, and that of the dudleyas by haworthias and gasterias. So far as outward form is concerned we have a case in which unrelated families have made closely similar development in the course of their adjustment to nearly identical climates. We can not yet be sure that these similar but unrelated forms are also alike in their physiological behavior, for the African plants have not been investigated in their native region.

Non-succulent Plants

On turning our attention from the succulent to the non-succulent desert plants we are confronted by a still larger number of species, in which there is even greater variety in those features of structure which are important in the vegetative processes of the plant and in its adjustment to environment. There are great differences in the duration of life of the individual plants and of their separate branches. In large woody forms the stem may have the normal type of structure found in hardwood trees or may depart from it in almost every feature. The surface of the stem may bear a rough bark or may be

smooth and green, carrying on the principal functions of the leaf.

In the non-succulents the leaf may be perennial, or it may appear only in the warm season, or only in the wet season, or may even require a season which is both wet and warm. The size of the leaves is greatly varied, but small ones predominate. In the richly branched palo verde (*Cercidium microphyllum*) there are minute leaves in the rainy seasons, but their total area is much less than that of the green twigs and stems that are doing most of their work. In the beautiful smoke tree of the Salton Basin (*Parosela spinosa*) there are leaves on the very young trees, but they are minute or absent on the old ones, and the crown is made up entirely of richly branched twigs. In the allthorn (*Holacantha emoryi*) there are leaves on the seedling for a few weeks, but the mature tree is green-stemmed and leafless.

Any one who travels through the desert will note that every tree and bush is full of dead twigs and often has large dead branches. These represent the backsets to growth which are due to exceptionally dry periods. In effect the twigs and branches are deciduous, much as the leaves are in hardwood trees. An ordinary rainless period of twelve to fifteen weeks will result in the death of all the leaves and branches of a large number of small bushes but only rarely in the destruction of the crowns of their root systems. After the next ensuing rainy season the plants will be as large as ever. This is precisely the manner of life of a number of ferns, which seem so much out of place in the desert. Certain species are really true and successful desert plants. Their drought-resistant protoplasm endures the unfavorable seasons without any of the elaborate mechanisms of the larger plants.

Degrees of Success

In our investigations with non-succulent plants we have been led to the view that they not only show different modes of adjustment to desert conditions but have achieved different degrees of success in it. Our criterion of success requires that a plant must have a large area of distribution, must be abundant in some part of its area, must show some degree of elasticity in its habitat requirements and must have solved the problem of withstanding the longest dry periods to which the normal climatic fluctuations subject it. Judged by these standards, not more than 20 per cent. of the species of non-succulents have achieved a high degree of success.

One of the noteworthy plants that shows every evidence of a nice adjustment to arid conditions is the creosote bush (*Larrea tridentata.*) Its behavior and water relations have been investigated at the Desert Laboratory by Dr. Mallery and by Dr. Runyon. They have found that this small-leaved evergreen shrub, which is so abundant from southern Nevada to San Luis Potosi, possesses few of the anatomical characters that are of common occurrence in desert plants and are of such a nature as to aid them in the conservation of water. The adjustments of *Larrea* to its arid environment are chiefly functional rather than structural. Also it exhibits an unusally high degree of what may be designated "physiological elasticity," by virtue of which its size, rate of growth, density of stand, amount of foliage, size and structure of leaves and size of seed crop vary within wide limits, according to habitat and season.

Physiological Behavior

It is necessary, therefore, in making an estimate of the diversity of desert plants to consider not only their conspicuous differences in form and structure but also to know something of their physiological behavior. Since this requires prolonged investigation of each species it is natural that our knowledge

of their functional features lags far behind our knowledge of their morphology.

The reduction of green surface which is universal in the cacti of the Sonoran Desert and very common in the non-succulents serves to decrease greatly the amount of food manufacturing that such plants are able to do. We still know little about the character of the photosynthetic process in green-stemmed leafless desert plants as compared with broad-leaved plants. Also we know little about the effect of low water supply and brilliant illumination on this important process. The development in cacti of the heavy surface which protects their moist tissues and the almost continuously closed position of their stomata are serious impediments to the free exchange of gases, which is so important in both photosynthesis and respiration. Enough work has been done on the physiology of some of the massive cacti to show that their respiratory behavior has many features of difference from that of non-succulent plants.

In recent work our interest has been attracted to several trees and shrubs which are abundant in the desert plains of Sonora and, like *Larrea*, have few obvious features of the sort that we are accustomed to regard as characteristic of desert plants. It is certain that an understanding of the place of these shrubs in nature must await investigation of their physiology, their life-histories under natural conditions and their probable origin and distributional movements.

Mesquite and Tésota

Prominent among these shrubs are members of the large family Leguminosae, which has contributed several highly modified species to the desert flora and is abundantly represented in the arid and semi-arid regions of all the continents. The most widely distributed leguminous trees in the North American deserts are the species of mesquite (*Prosopis*). In general appearance the mature plant resembles a peach or apple tree. The leaves are compound and the leaflets very small. It is only in the most favorable situations that the mesquite is found as a tree. In less favorable ones it is merely a shrub. Its roots often extend to a depth of 40 feet in the alluvial clay of flood-plains.

Work on the physiology of the roots as well as on the moisture conditions in deep soil has helped to elucidate the abundance and rapid growth of this tree. It is winter-deciduous and its new foliage appears in the spring at the very time that the winter ephemerals are dying from drought, and every week is hotter and drier than the last. The roots are able to function at the cool temperature of the lower soil levels and at that depth can secure water from a supply which is nearly constant throughout the year. Thus are the mesquites of the flood-plains able to expose their great extent of leaf surface without danger of insufficient water supply.

On the desert plains, where the mesquites are uncommon and small, the soil is shallow or filled with calcareous hardpan, and there is no deep-seated accumulation of water. Work has been done on the daily course of water loss from small mesquite trees in dry situations in dry months. Atmospheric evaporation rises rapidly from sunrise to a maximum at 1 or 2 o'clock in the afternoon. The loss of water by the mesquite also begins to rise rapidly at sunrise and its hourly increase continues until 9 or 10 A.M. Then comes a sudden break in the rate of loss, which falls to its early morning amount and remains there until 4 or 5 P.M. The tree does not prodigally throw off more water than it is able to get out of the soil and to transmit to its leaves at times when the evaporation is very high.

Considerable work has been done at the Desert Laboratory on the mecha-

nisms which enable a plant to control its loss of water. The closing of stomata, rising osmotic value of sap and changes in the manner in which the water is held, or "bound," are all of importance. Also there is evidence that a high rate of loss breaks the continuity of the minute columns of water that are moving toward the leaves. This is probably the principal cause of the mid-morning check in the rate of water loss by the mesquite. The night is important in bringing conditions that enable plants to restore the continuity of their water movement and the moisture content of their tissues. As Livingston once said, "If the celestial machinery should break down so that just one night was omitted in the midst of a dry season it would spell the doom of half the non-succulent plants in the desert."

Another leguminous tree, the tésota (*Olneya*), has gone further than the mesquite in emancipating itself from favorable localities and in surviving in the driest parts of the Sonoran Desert. In every visible feature that might concern the water relations tésota closely resembles mesquite. Further investigation is needed to uncover their differences. Tésota is the only member of the genus *Olneya*. Its geographical range is nearly coincident with that of the Sonoran Desert. Its nearest relatives are certain trees and shrubs (*Eysenhardtia, Willardia*) found in and near the southern part of the Sonoran Desert, all of them with a water requirement higher than in tésota. The manner in which mesquite is pushing out from the favorable flood-plains on to the unfavorable desert and developing water-conserving habits suggests the possible history of the tésota. It is now far from its nearest relatives in the characters on which its classification depends and also in those that determine the sort of region and habitat in which it grows.

As is well illustrated in the case of mesquite and tésota, the behavior of a desert plant and its place in nature can be learned only through the conjunction of detailed laboratory work and widely extended observation in the field. The

HEAVY TYPE OF VEGETATION

FOUND ON GRANITIC SOIL IN THE PLAINS OF WESTERN SONORA. CONSPICUOUS PLANTS ARE *Fouquieria splendens, Olneya tésota, Opuntia thurberi* AND *Franseria deltoidea.*

Desert Laboratory offers almost ideal opportunities for the employment of intensive and extensive methods in the pursuit of its problems.

The Sonoran Desert

The boundary of the Sonoran Desert is sharp in certain places where the topography is rugged and the climatic change abrupt. Its northwestern and southern limits are indefinite, for in the former it merges gradually into the Mojave Desert, and in the latter passes by easy stages into thorn-forest. Most of the thorn-forest region, which stretches south for 1,500 miles along the west coast of Mexico, is semi-arid, but it merges along its eastern edge into humid mountain forests and jungles. It is the link between desert and tropics in western North America.

It is well known that the climatic fluctuations of recent geological time brought about profound changes in the plant life of northern North America. The advance and retreat of the extensive ice sheets was accompanied by movements of plant species and of types of vegetation which were alternately pushed south or given an opportunity to move north. The immediate effect of the presence or retreat of the ice sheets was local, but the fluctuations of climate which controlled the ice were far-reaching. There is physiographic evidence in the Sonoran Desert that there have been fluctuations in its rainfall in recent geological time, and it is presumed that there were accompanying fluctuations in temperature.

Very little is known about the amplitude of the pulsations, and their chronology can only be presumed to have a close relation to that which has been tentatively worked out in the north. So closely are the limits of the desert determined by climatic conditions to-day that we can see how surely every change of climate was followed by the movement of plants. On the southern edge of the Sonoran Desert the pulsations have been particularly important, for the thorn-forest has a large flora and every wetter or warmer period has permitted some of its species to travel north.

Migration Paths

If we examine a map of the Sonoran Desert we will note that there are long stretches of country lying in a nearly north and south position which are not broken by large bodies of water or lofty transverse mountain ranges. These stretches have afforded paths along which it has been possible for plants to move north or south as the climatic conditions have slowly changed. From the northern edge of the Mojave Desert southward along the coastal plains of Sonora for 1,000 miles is a path through open country at low elevations, which we designate the Coastal Path.

A second runs parallel to the first through Baja California, traversing country more rugged but also low in elevation—the Peninsular Path. A third runs through the foothills of Sonora and Arizona at altitudes of 2,000 to 4,000 feet—the Foothill Path. A fourth lies in the higher mountains of the Sierra Madre and ends in the scattered ranges of southeastern Arizona—the Mountain Path. Far to the east in the Chihuahuan Desert doubtless lie other paths which have not yet been investigated or defined.

The two paths which border the Gulf of California are of particular interest, because they lie at the same low elevation and are closely parallel in their climatic character. The Foothill Path runs through country which is somewhat cooler and less arid than the coasts of the Gulf. The Mountain Path is wholly outside the desert but has some important relations to the Foothill Path. Whatever general changes of climate may have affected the Sonoran Desert region in recent geological time, the

three mainland paths have continuously differed from each other in climate as much as they do to-day.

Evidence that the four paths have served for extended movements of plants is based on the study of the distribution of the common species of the area. The majority of them range north and south for much greater distances than they do east and west. Plants in the Peninsular and Coastal Paths have had a physical barrier in the Gulf of California, which has made interchange between them difficult. Plants in the three mainland paths have had climatic barriers which served to lessen the ready movement of plants out of one path into another. In each path it has been easier for plants to advance or retreat for a long distance north or south than to move a short distance east or west into the adjacent path. Thus have come about the long narrow distributional areas that characterize so many species.

In order to understand events in the Sonoran Desert it is necessary to know something about the regions adjacent to it. Some of its plants are merely the remote pioneers of groups that have their principal development far to the north or south. There are many cases in which a genus of plants is represented by several species at the southern end of one of the paths but loses them one by one as the path stretches northward, until only one species crosses the International Boundary. The same thing is true of the southward movement of numerous genera that have their present centers of development in the Mojave Desert or the Great Basin.

Agencies in Evolutionary Development

It must be remembered that the plant migrations we are considering took place very slowly over periods of thousands of years. In some cases the very same species advanced, retreated and advanced again with little or no change in its identity. There is abundant evidence, however, that climatic variations, changes of surface and soil and enforced movements have been important agencies in

VEGETATION OF A GRANITIC PLAIN

NEAR PUNTA PRIETA, BAJA CALIFORNIA, WITH THE GIANT CACTUS *Pachycereus pringlei*, *Idria columnaris*, THE FAT-STEMMED TREE *Pachycormus discolor* AND *Agave nelsoni*.

LANDSCAPE DOMINATED BY *YUCCA VALIDA*

ON THE INNER EDGE OF THE VISCAIÑO DESERT, IN BAJA CALIFORNIA. THE CACTI *Machaerocereus gummosus* AND *Opuntia calmalliana* ARE ABUNDANT.

shaping the evolutionary development of plants. The genera and species which are found only in the Sonoran Desert are the product of these agencies. In several of the groups endemic to the area there are series of related species, occupying areas which overlap very little and lie in a chain along one of the paths of movement. Such unbroken chains, which combine evidence of migratory movement linked with evolutionary activity, appear to be relatively recent in their formation. If they were old there would be more distant relationship between the links, the chain would be broken, and some of the links would be gone.

One of the cases in which the evolutionary history of a genus is illuminated by the geographic distribution of its species is the group of barrel cacti of the genus *Ferocactus*. There are thirty-two species of these, twenty-four of which are either local or very poorly known. The other eight are of wide distribution and play an important part in the vegetation of their respective areas. In the cactus genus *Opuntia* similar chains extend from the south, with slender links in Sinaloa and southern Sonora, and end in the Gila or Colorado valleys with a strong cluster of forms. The inference is strong that in such groups as *Ferocactus* and *Opuntia* there has been steady movement accompanied by the appearance of new species and that these phenomena have taken place in very recent time in the geological sense.

It is natural that we have more evidence of recent events than of older ones, as the later movements have done much to obscure the earlier. In a few cases, however, single widely separated links have been found which are recognized as belonging to the same chain, broken and scattered long ago. There are genera in which the species do not show a close relationship and are now distributed irregularly around the end of one of the paths of migration. There are species which exhibit a scattered and discontinuous distribution, which is uncommon among the dominant plants of the area.

It is obvious that these are cases in which the genus or the species has lost some of the ground which it formerly occupied. The genus is no longer distributed in such a way as to give a hint of the sequential relation of its members. The species is no longer distributed so as to accord with the majority of plants that now range along the lanes of migration, nor does it occupy all the area in which the conditions are favorable for it. The evidence suggests that these plants belong to an older wave of movement. Indeed, it is possible that some of them have endured all the climatic pulsations of the Pleistocene and Recent periods and have either made repeated movements or else have stood their ground and developed the ability to live under a wider amplitude of physical conditions than some of their associates have.

The historical problems raised in our work on the Sonoran Desert are very fascinating, in spite of the difficulty in securing full and conclusive solutions to them. In the recent history little help is to be anticipated from fossil records. Desert conditions are not favorable for the preservation of plant remains, and those that are found in old lake beds or alluvium are apt to be misleading. An interest in the historical background of our problems does much to enlighten the more concrete and equally important work of studying the relation of the present vegetation to the soils, climate and other physical agencies of to-day.

Sonoran Climate

The Sonoran Desert stretches from Lat. 24° N. to Lat. 35° N., lying at the southern edge of the temperate zone. This means that its area embraces differences in winter temperature which are important to plants. Along the northern edge there are from twelve to sixteen weeks of the winter season in which frost is apt to occur and in which the minimum temperature may fall for a few hours as low as 16 to 20° F. At the southern edge frosts are light and infrequent. Summer temperatures are high throughout the area.

The distribution of mountains and large bodies of water is such that differences of latitude affect the duration of the hottest season but do not have a consistent influence on the highest temperatures that are reached. The influence of high temperatures on the distribution and physiological performance of plants is registered in intimate connection with the influences of restricted soil moisture and high rates of transpiration. The influence of low temperatures is much less intimately connected with the water relations, at least in non-succulent plants.

Our work indicates that the poverty of the flora in the driest parts of the Sonoran Desert is due as much to the joint influence of aridity and the low temperatures of winter as it is to the aridity alone. The warmer southern edge of the desert has many species of perennial plants which are highly drought-resistant but are not able to push north into the region of heavy frost. Detailed investigation of the relation of topography to the distribution of low temperatures has enabled us to appreciate the fact that these plants have their northernmost occurrence in the warmest spots. Whether any of them are capable of ranging still further north requires the test of experimental cultures, the results of which may indicate that certain species have not yet reached the northernmost limit at which they can grow.

The differences in rainfall which are found in the Sonoran Desert are wholly independent of latitude and are controlled by the larger air movements, modified by the influences exerted through differences of altitude and through the distribution of large mountain ranges. The most arid part of the desert lies on the eastern or lee side of the great mountain ranges of northern Baja California and southern California. Almost equally arid are the Pacific and Gulf

THE HEAVIEST VEGETATION OF A TRULY DESERT TYPE

IN THE NORTHERN HALF OF THE SONORAN DESERT IS FOUND ON OUTWASH PLAINS NEAR LARGE MOUNTAINS AT ELEVATIONS BETWEEN 2,000 AND 3,000 FEET.

coasts of Baja California and the Gulf coast of Sonora. Along the Pacific coast the atmospheric humidity ranges higher than in the interior, and at certain seasons there is morning fog for ten or fifteen miles inland. These conditions favor the growth of lichens and the air plant *Tillandsia,* but they do little to ameliorate, for larger plants, the effects of dry soil and incessant wind.

It means little to say that nearly half of the Sonoran Desert has a mean annual rainfall of less than five inches. It is the irregularity of the rain storms and the long periods of drought which are of importance. In Baja California the town of Santa Rosalia, after four years with no rain, was visited by a downpour of three inches in two hours in August, 1933. Even after several rainless years leaves will be found in the spring on *Idria,* flowers on *Pachycereus* and leaves and flowers on *Viscainoa.* After one of the heavy downpours there is a prompt response on the part of all classes of plants. About once in every eight to fifteen years the driest sections of the desert are visited by successive rains. Only at such times is it possible to determine the full extent of the flora, the complete make-up of the vegetation and the optimum growth and development of the plants.

The inner edge of the Sonoran Desert, from the Gila River to the southern boundary, has an average annual precipitation ranging from eight to fifteen inches. In this territory there are two rainy seasons and the periods of drought are therefore much shorter than they are on the Pacific coast or along the western edge of the desert.

Sonoran Vegetation

The differences of climate which may be found in the various parts of the Sonoran Desert, together with the varied character of its topography and sharp differences in the nature of its soils, all serve to give the vegetation greater variety than might be expected in a region which presents so many obstacles to the best development of plants. The limited number of species of woody perennials to be found in the driest sections serves to make the presence or absence of a single species more important in the physiognomy of the vegetation and the appearance of the landscape than would be the case if a rich flora existed there.

A comparison of the communities reveals almost every gradation in the features which characterize desert vegetation. The prevailing stature of the dominant plants is low, but varies from pure stands of *Atriplex* or *Franseria* less than 10 inches high to open forests of *Olneya* or *Cercidium* fifteen to twenty-five feet in height. The spacing of the individuals is characteristically wide, but it varies from stands in which there are many bare places with a diameter of forty feet to others in which the branches of the shrubs almost meet.

An intermingling of diverse types of plants is another typical feature in which there is variation from local colonies of a single species to extensive areas of great variety. Still further differentiation is given the most widely separated parts of the Sonoran Desert by the distributional limitation of its common and characteristic plants. In fact there are very few perennials of importance in the make-up of the vegetation which are found throughout the area.

The plains and mountains which border the lower course of the Colorado River and the head of the Gulf of California have the smallest flora and the most scanty vegetation of any part of the North American Desert. One may walk across the outwash plains of Yuma County, Arizona, for a long distance without being able to count more than sixteen species of perennials, and the vegetation is so open that it is possible to walk a straight course with few deviations. The most abundant plants are the creosote bush (*Larrea tridentata*)

and the chamiso (*Franseria dumosa*). Along the streamways are occasional large individuals of tésota, smoke tree or ocotillo. On the hills and mountain slopes there are a few widely separated shrubs and cacti, but at a short distance most of the mountain ranges appear to be wholly devoid of plants.

In Baja California

In central Baja California the rugged volcanic surface bears an open stand of small shrubs together with scattered individuals of the unique cirio (*Idria columnaris*), the cardon cactus (*Pachycereus pringlei*) and large century plants. In broad plains with deeper soil are to be found fine examples of some of the plants which are confined to Baja California, including cirio, with its heavy erect trunk bristling with short branches, and the torote (*Pachycormus discolor*), a beautiful little tree with smooth cream-colored stems, the size of which is out of all proportion to the height of the tree.

Two hundred miles farther south the cirio has been left behind and the landscape is dominated by a tall yucca (*Yucca valida*), several abundant cacti, and another ocotillo (*Fouquieria peninsularis*), with poorly branched widely divergent arms. The southernmost areas of desert in Baja California still have all the earmarks of arid country, but there is a pronounced thickening of the stand, an increase in the number of tall individuals, an even greater display of plant types and a much richer perennial flora. Here are slender erect types of cacti well suited to live in the scrub, numerous drought-deciduous shrubs and occasional flat-topped acacia trees, the dominant plants of the thorn-forest area which occupies part of the cape district of the peninsula and stretches far to the south on the mainland.

In the foothills of the mountains of southern Baja California and in the narrow valleys which traverse the arid volcanic mesas is to be found an almost luxuriant vegetation with a blending of the ecological features of desert and tropics, a mixture of their respective plant types and a mingling of their floras.

Near the head of the Gulf of California its eastern and western coasts are very similar in their vegetation. On traveling eastward from that region on to the higher outwash plains around Phoenix and Tucson there is a conspicuous change in the vegetation. There are more plants per acre, more large individuals and more kinds of plants. It is in this region that the cacti are most abundant and diversified, broad plains are more completely covered by the creosote bush, and coarser slopes bear open miniature forests of palo verde and tésota.

South of International Boundary

South of the International Boundary is a vast plain which rises gradually from the Gulf of California, is studded with hills and small mountains and narrows gradually toward the south. The vegetation of this region, which comprises nearly half of the state of Sonora, differs in many respects from that found at the same latitudes in Baja California. Over extensive areas the tésota and the low gray shrub incienso (*Encelia farinosa*) are the dominant plants, with the creosote bush restricted in its occurrences and the cactus display much less impressive than it is in Arizona. Three species of palo verde and the mesquite are abundant on the most favorable soils, in the bottomlands of the broad valleys, while on the least favorable ones there is a low and open stand of salt bushes or chamiso.

Between 100 and 200 miles south of the International Boundary the hilly country which forms the inner edge of the Sonoran Desert is strikingly different from the plains of the coastal region. Slightly greater rainfall and slightly

milder winter temperatures do much to improve the conditions for plants, but the climate is still distinctly an arid one. It is here that many trees and shrubs are found which are drought resistant but not frost resistant. They mingle with the plants which range further north and the two groups occupy the same terrain without severe competition and with resulting increase in the density of the vegetation.

In Southern Sonora

As the coastal plain grows narrower in southern Sonora and the mountain background lies nearer the coast, there is a marked change in the vegetation of both hills and plains. The general features of this change are like those found in Baja California, but it is more gradual in Sonora and takes place somewhat farther north. South of the Yaqui River there is much of the desert in which it is not possible to walk a straight course for more than a few yards, or to go very far without the use of a machete. The stature of the trees has increased very little, but their number per acre is much greater. Smaller plants are no longer clustered more densely in the shade of the trees but grow everywhere. Streamways are no longer discernible at a distance by their fringe of heavier vegetation but only by their slightly taller trees and their dense thickets of shrubs and vines. The cacti of the open desert begin to give way to species which endure the shade of the thin tree-tops. The soil reacts to the heavier vegetation and contains much more organic matter. The runoff is more gentle and the larger streamways have pebbly bottoms and rounded banks which form a sharp contrast to the sandy bottoms and steep bare banks of the streamways which carry only the violent flash floods of the more arid parts of the desert.

From the conditions in the Yaqui Valley it is only a short step to those in the valleys of the Mayo and Fuerte, where the characteristics of the thorn-forest prevail over those of the desert. This is one of the most interesting of the many places in which it is possible to study the gradual changes which lead from the desert to other types of plant life.

Biological Work in the Desert

The value of biological work in the desert resides largely in the fact that organisms may there be studied under extreme conditions. The physiological behavior of the individual and the evolutionary development of the race may both be investigated as they manifest themselves in an adverse environment. Even within the desert, however, there are localities and habitats which are more extreme and others which are less so. In our work we have found it instructive to study the entire range of conditions, for in the heart of the desert we find the few plants which are most closely adjusted to great aridity, and along the edge we find forms only imperfectly suited to it, from which there will doubtless develop in time new species capable of penetrating to the center of the desert.

The most important aim of our work is to keep in view the vast array of influences and circumstances that have determined the history of desert plants and now determine the life and survival of every one of them. We need the results of highly specialized work, but we need even more to interpret these results through an intimate knowledge of the plants on their dusty alkaline plains or sun-baked volcanic hills. Especially do we need to weave together the separate threads of knowledge about the plants and their natural setting into a close fabric of understanding on which it will be possible to see the whole pattern and design of desert life.

SCIENTIFIC METHOD IN THE INVESTIGATION OF ECONOMIC PROBLEMS[1]

By Dr. HAROLD G. MOULTON

PRESIDENT, THE BROOKINGS INSTITUTION, WASHINGTON, D. C.

ALTHOUGH the so-called science of economics is as old as the American Republic, discussions still persist as to whether the subject can in any true sense be regarded as scientific in character. Indeed, as a result of the economic disorganization of the present day and the confusion of counsel which exists, the question is raised more often now than in former times.

I begin by saying that there is no such thing as *the* scientific method. There are as many different scientific methods as there are different fields of knowledge; in fact, various types of methods may be used within any given field or even in a single investigation. Being scientific is a matter of *spirit* and not of *method*. This spirit is not the exclusive possession of the scholars in any particular realm of inquiry.

It is not my purpose to assert that all economists are imbued with a truly scientific spirit; on the contrary, I believe that the percentage of workers in the field of economics who are unscientific, at least in certain respects, is much greater than that in the natural sciences. We doubtless have more than our share of charlatans, special pleaders, reformers and incompetents—for it is, unfortunately, even easier for the economic quack to gain a hearing than it is for the astrologer and the phrenologist.

If a better understanding is to be developed between natural scientists and economists, it is essential that I speak plainly with reference to a prevailing tendency. Mathematicians, physicists and engineers often assume that economists have never had a course in mathematics, logic or physics, and that the scientific method is a sealed mystery to us. When, however, they turn to writing on economic subjects they frequently display a lack of scientific attitude which is to us truly appalling.

Other natural scientists and mathematicians, while not presuming to speak authoritatively on economics, are nevertheless convinced that what economics really needs is a few first-class men thoroughly trained in mathematics or some other field of the natural sciences.

For example, a distinguished engineer, in a recent volume, starts out by implying that economics has heretofore been wholly unscientific in character and that we must look to engineers trained in the precise methodology of mathematics and engineering to find a solution of our economic difficulties. He states in his introduction: "When we come right down to it, the engineer designed the mechanism of the [economic] system even if he had nothing to do with the design and application of the control devices. Therefore he ought to be able to say why it does not function in a proper manner." It is incredible to me that one trained in precise thinking should be unable to see the *non-sequitur* in this statement. The fact that engineers build bridges or industrial plant and equipment of course provides no basis whatever for an understanding of the "control devices" with which economics is primarily concerned.

This author then goes on to state that "no one seems to have approached the problem from the production end instead

[1] Address at the St. Louis meeting of the American Association for the Advancement of Science, January 2, 1936.

of from the consumption terminus." Now even a slight acquaintanceship with economic literature would have revealed that the whole classical system of economic analysis approaches the problem from the production end; indeed, it is only in comparatively recent times that a correction has been attempted by attaching more importance to consumption in relation to production.

It is not open to dispute that the training in close, precise thinking that mathematics affords is of the greatest importance. It is also true that mathematics is a useful tool for economics. The application of mathematical methods has rendered much service in connection with the study of statistical averages and probabilities, and in measuring the degree of consilience between correlated statistical data. But it does not follow from this that a mathematician can carry over his general methodology into economics and obtain fruitful results any more than he can carry it into biology or medicine and discover new truths.

It is not commonly realized that a considerable number of men possessed of a thorough training in science and mathematics have undertaken to apply their methodology in the field of economics —from Simon Newcomb to Frederick Soddy. In the main, these men have tended to over-simplify the problems involved, to make naive abstractions and unreal assumptions and thus to obscure rather than reveal the truth. Their lack of familiarity with actual economic processes and relationships proves their undoing.

There are of course exceptions to the generalization that natural scientists have not made great contributions in economics. The chief of these is Alfred Marshall, who published his great volume entitled "Principles of Economics" in 1890. Marshall's was admitted to be one of the really great minds of the second half of the nineteenth century. His early training was in the field of mathematics and psychology, and he had reached mature years before he began the systematic study of economics. While he made considerable use of mathematical tools, he came to see clearly that the mathematical method was of limited applicability in the discovery of economic truth. He pointed out that the more a complex problem is broken up for purposes of study with a view to segregating disturbing influences by the assumption *other things being equal,* the less closely do the results correspond to real life. He wrote:

> I had a growing feeling in the later years of my work that a good mathematical theorem dealing with economic hypotheses was very unlikely to be good economics: and I went more and more on the following rules: (1) Use mathematics as a shorthand language, rather than as an engine of inquiry. (2) Keep to them [these mathematical symbols] till you have done. (3) Translate into English. (4) Then illustrate by examples that are important in real life. (5) Burn the mathematics. (6) If you can't succeed in (4) [that is, in illustrating by examples that are important in real life], burn (3) [that is, the English statement of the principles deduced]. This last I did often.

Even though the first assumptions may be realistic, the conclusions derived by the process of isolating disturbing variables may be quite invalid as explanations of the actual world. This is why Marshall advises against mathematics as a method of inquiry.

Let me say again in conclusion that I do not wish to be interpreted as holding that mathematics has not been a useful tool in connection with economic analysis and that it may not be made more useful in the future. While I should be distrustful of completely independent work on the part of a mathematician in the field of economics, I should, on the other hand, be quite hopeful of important results being achieved through close collaboration between mathematically trained workers and economists inti-

mately acquainted with the processes of the complex economic system.

Economics in a Changing World

My primary object on this occasion, however, is not to discuss the applicability of mathematical methods to economic analysis, but to point out why we must expect a larger measure of disagreement among economists than is likely to be found in any division of the natural sciences and why, in the nature of the case, we can not expect to formulate a complete set of economic principles of universal and eternal applicability. At the conclusion of this discussion I shall present for your consideration the methodology employed in a recent investigation in economics with which I have been associated in order that you may see the character of the methods which have been employed.

As a point of departure I must point out that early writers in the field of the social sciences were directly under the spell of the scientific spirit and the scientific outlook which had already developed in the fields of astronomy, mathematics and physics. It will be recalled that it was in the sixteenth and seventeenth centuries that such men as Galileo, Kepler and Newton discovered and formulated some of the basic laws which govern the physical world. In the course of the ensuing century these scientific discoveries came to exert a profound influence upon men's ideas in other realms of thought. It came to be asked whether man himself was not as much a part of and controlled by an orderly universe as the physical earth on which he lived.

The great problem appeared to be to discover the laws which govern human action and, through human action, social and economic progress. Early writers, such as Blackstone, Rousseau, Godwin and Adam Smith, found the answer in a system of *natural law* which, if not interfered with by governments or other human institutions, would always lead to progress.

During the century ending in 1850 a body of economic principles was gradually evolved. An elaborate system of economic conclusions was developed on the basis of a comparatively few simple laws which were rooted in physical factors. Among these may be mentioned, for purposes of illustration, the following general principles: (1) the law of diminishing returns, which holds that beyond a certain point the application of additional labor and capital to a given amount of natural resources does not yield a proportional increase of product; (2) the law of diminishing utility, which holds that beyond a certain point the satisfaction derived from the consumption of additional units of any given commodity declines; and (3) the law of the variability of human desires, which holds that human wants as a whole are virtually insatiable.

The extension of economic activity throughout the world, the development of infinitely varied types of product and the whole complex system of production and distribution, involving varying and constantly changing commodity values, are the direct results of these fundamental attributes of nature and of man. These underlying principles or laws, and also a great number of secondary principles derived therefrom or articulated therewith, have long been the subject of universal agreement among economists.

It is true, however, that there are many differences of view among reputable economists with reference to issues of primary significance, and it is true that the extent of agreement is vastly less at this particular juncture in the development of economic thought than was formerly the case. After John Stuart Mill published his great treatise in 1848 it was believed, in the Anglo-Saxon world, that almost the last word on political economy had been written—that Mill's analysis had rounded out a body of economic principles that would remain forever as an adequate explana-

tion of the operation of economic forces. In 1850 economics was as settled and complete as the science of physics was considered to be in 1890.

In the ensuing forty years, however, a group of continental economists, chiefly Austrian, approached the problem from a somewhat different angle, giving much more weight to psychological factors affecting human conduct and hence the laws of value and distribution. In 1890, as already indicated, Alfred Marshall brought out his principles of economics which integrated the analyses of the Austrians with those of the English classical school and showed how the two might be harmonized.

To-day, as a result of changes to which I shall presently refer, a considerable part of the formerly accepted body of economic doctrine is subject to challenge, and some of it has been definitely dethroned. One reason is that the accumulation of a vast body of recorded data bearing upon economic issues has made it possible to test the validity of many of the assumptions on which the classical analyses were based. However, a more fundamentally important factor has been the changing character of the economic system itself.

And here I come to a statement of what I conceive to be the basic difference between economics and the natural sciences. While the underlying principles of economics are based upon natural forces, the economic system by means of which productive activities are carried out is constantly undergoing evolutionary change. The natural sciences, on the other hand, are concerned with the observation of physical forces which are practically permanent in character. The complex economic machine which has resulted from certain natural laws and the growth of human institutions has undergone a rapid evolution even in the course of our own life span. Time is not available in which to cite concrete illustrations of the way in which the economic machine has changed in character. It must suffice for the present purpose to point out that *as* it changes economic thought must perforce be modified to take account of the working of the system under new conditions. A phrase *—the relativity of economic thought—* has been developed to indicate the necessity of an evolutionary body of economic thought paralleling evolutionary changes in the economic system. In a dynamic world we must perforce have a pragmatic economics.

In view of the constantly changing character of the economic system, it is not surprising that there should be at a time such as the present wide differences of opinion among economists. In the nature of the case we do not all have the same body of factual data at our command; and our interpretations of the way in which the economic machine operates at any given time will in consequence vary. The degree of disagreement is, moreover, increased as a result of the fact that some economists are constantly endeavoring through the study of quantitative data to discover new light, while others prefer to hold fast to the accepted body of doctrine.

The history of human thought in all lines reveals a type of person who is reluctant to relinquish old concepts and conclusions in favor of new ones. It is found, I am told, even in physics and mathematics. Although the necessity of a flexible and evolutionary thought is particularly necessary in economics—in view of the changing character of the economic system—the tendency to adhere steadfastly to the principles laid down by our predecessors is, I believe, particularly marked. I am sometimes reminded of the mother who warned her son when he went to college not to let these university teachings unsettle his religious beliefs. Upon returning from college the young man confessed that some of the things which he had learned necessitated a modification of the relig-

ious views which he had formerly held. After giving the matter consideration for a moment the mother said: "Well, my son, we will hope that it isn't true; but if we find that it is we will keep still about it."

The evolutionary character of the economic system, necessitating an accompanying evolution of economic thought, produces quite different reactions in the minds of different scholars. To the individual in quest of the ultimate, as many economists have been, it is discouraging, even demoralizing, to discover that changing conditions necessitate the abandonment or modification of cherished beliefs. To the individual who finds his greatest satisfaction in the perpetual discovery of new truths, however impermanent in character they may prove to be, the fact that the economic world constantly undergoes change only heightens the intellectual satisfaction derived from the study of economics. The vein can not be worked out; the quest for knowledge and understanding is never ending.

Now if it be true that the economic world, which is the subject of the economists' study, is undergoing constant change, does it not follow that economics can never hope to be an *exact science?* The answer is clearly yes, if one means by exact absolutely precise and permanently unchanging. But it is not true that at any given period of time it is impossible to prove anything, that it is all guesswork, that one man's conclusion is as good as another's.

There is a considerable body of principles that remain always true—though they are sometimes overlooked or forgotten, even in the halls of Parliament. Moreover, it is becoming increasingly possible to subject debatable issues to statistical verification—though as yet the data often lack the precision we should like. Owing to the great progress which is being made in the systematic recording of factual information—which constitutes our primary laboratory material—I foresee in the next generation a substantial narrowing of the area of disagreement as to the working of economic forces. But economics will still not be as *exact* as mathematics.

Economic Methodology Concretely Illustrated

I shall now turn from these general considerations to a specific economic investigation, for the purpose of indicating the character of the methodology involved. As I have already indicated, varying economic problems require somewhat different methods of analysis; indeed, a single problem may involve a combination of methods. The investigation which I shall use for purposes of illustration is that recently concluded by the Brookings Institution under the general title, "The Distribution of Wealth and Income in Relation to Economic Progress." Because of the repercussions of a retarded rate of economic growth upon the practical application to productive processes of the results of scientific investigations in the field of the natural sciences, I trust you may be interested in the analysis itself as well as in the question of methodology.

The very wording of the title—the distribution of income in relation to economic progress—which was chosen before the investigation was begun—suggests that we had some sort of an hypothesis which we were interested in testing. The apparent fact that business enterprises seldom produce at full capacity, and that the greatest problem of business managers appears to be to find adequate markets for their products, had raised in the minds of many business men and economists the question, "Does not a lack of purchasing power among the masses perhaps serve to prevent the full employment of our productive resources?" And this thought led at

once to the correlative question, "What is the possible bearing of the distribution of income among the different groups in society upon the demand for the products of industry?"

Views both as to the facts about production and as to the possible effects of an unequal division of income upon the functioning of the economic system were widely at variance. It was our belief that a searching study into the interrelations between production and consumption as revealed by data and information drawn from the actual world of affairs might yield results of basic significance. I must make it clear at this place that we were not directly concerned with ascertaining the causes of depression. Our interest was in discovering whether, even in periods of prosperity, there might be in operation factors or forces which impeded the full utilization of our economic resources.

In order to reveal the character of the investigation required and the methods employed, I shall describe very briefly the several steps that were involved in the analysis.

Step 1. The first step was to ascertain the degree to which our productive resources are, in fact, utilized. If investigation should show that in a period of prosperity such as that of the late twenties they were employed at full practical capacity, then it would be unnecessary to carry the investigation further. We surveyed statistical and other data bearing upon the productive output of the different divisions of our economic system, including mining, manufacturing, etc. We made allowances for numerous practical problems confronting the various industries which might as a practical matter reduce actual capacity below theoretical possibilities. In the more difficult cases, we checked our findings with representatives of the industries concerned, with a view to making sure that we had not overlooked any practical considerations. We found, in brief, that in the prosperity period of the twenties our productive facilities were used to approximately 80 per cent. of capacity.

You will wish to know whether the character of the investigation was not such as to leave room for a vitiating margin of error. We concede that the figure of 80 per cent. as a general average for American industry as a whole is not precise; the true level of operation might conceivably have been as low as 75 per cent. or as high as 85 per cent. The substantial accuracy of this estimate of the amount of economic slack was confirmed by the percentage of increase that occurred in the war time when industry operated at forced draft.

In any case, our first finding was of fundamental importance. The facts showed beyond question that—for some reason or other—the economic system, even in a period of great prosperity, was running at substantially less than a capacity basis. Analysis of the data as far back as to 1900, moreover, showed that such a situation had long been characteristic of American industry.

Step 2. The second task was to determine whether the failure to utilize our productive capacity fully might possibly be explained by any impediments or maladjustments within the *productive* mechanism itself. We were unable to discover any bottleneck, weak link or defective part in the productive machine. That is to say, there was no shortage either of raw materials, industrial plant and equipment, power or fuel, transportation facilities, money or credit or labor, which might explain the failure of the system as a whole to operate on a capacity basis. The source of difficulty had, therefore, to be sought outside the productive machinery.

Step 3. As the next step, we turned to a study of the distribution side of the economic system. Might the difficulty be found in a maladjustment between

productive capacity and purchasing capacity? To throw light on this question it was necessary to show how the national income is divided among the various groups which comprise the body politic.

For this purpose we had available reasonably satisfactory data with reference to the incomes of the American people. We found an extraordinarily wide dispersion in the distribution of income. In the higher ranges, incomes were in excess of any normal consumptive requirements; but the great masses of the population had incomes insufficient for primary requirements. There exists a *potential* demand vastly greater than could have been supplied had we operated our economic system at full capacity. Over the period from 1900 to 1929, the poor were not growing poorer, but richer. But the rate of income growth was, nevertheless, more rapid in the upper strata.

Step 4. The fourth step was to determine the effect of this unequal division of income upon the allocation of the total income as between spending for consumption and saving for investment. We found that the savings of those in income groups below $2,000 were negligible, while those in the higher income brackets saved a substantial percentage of their total incomes. Out of 15 billion dollars of individual savings in 1929, something like 13 billions was made by 10 per cent. of the population. Since the number of people in the higher income groups was increasing, the percentage of the total national income that was diverted to investment channels was increasing.

For this phase of the investigation the data were less satisfactory and precise. The margin of error in estimating the percentage of savings made by the upper income groups might possibly be as great as 20 per cent. Even so, two basic facts were clearly established: First, the great bulk of the savings is made by a small percentage of the population; and, second, owing to the rapid growth of income at the top of the scale, the percentage of the total income that is diverted to savings channels was tending to increase.

Step 5. The fifth step involved a problem of a different character. Granted that the existing distribution of income tends to increase the flow of funds into savings as compared with consumptive channels, does this fact serve in any way to impede the operation of the economic system? To answer this question it was necessary to study the forces which govern the transformation of the money savings of individuals into new capital equipment. This portion of the investigation required, first, analysis, and second, statistical verification. It should be stated at this place, moreover, that our conclusions in this connection are fundamentally at variance with hitherto accepted theories.

According to traditional views the greater the amount of money that is directed into investment channels the better, for it will all automatically be used in employing labor and materials in the construction of new plant and equipment—thereby increasing products capacity, and hence consumption, in the future. It had been assumed that when one saves money he simply exercises a demand for capital goods instead of for consumption goods, and that in consequence the production of the latter would increase, while that of the former would decline. Such an assumption, it will be noted, implied that consumptive demand and the demand for capital goods are independent variables.

Another line of reasoning, however, as well as observation of the actual processes of the business world, suggested that a declining consumptive demand might of itself deter the construction of new plant and equipment, even though funds were available for the purpose. Since new plant and equipment are constructed

with a view to expanding the output of consumption goods, does not consumptive demand constitute basically and ultimately the real demand for new capital? That is, instead of the demand for capital goods being derived directly from the money savings of individuals, is it not rather derived indirectly from the demand for consumption goods?

Conceding the fact that ultimately the profitable use of new plant and equipment depends upon an expanding consumptive demand, it has nevertheless been traditionally assumed that business enterprises would build new plant and equipment even though consumptive demand were declining—in anticipation of an ultimate increase in consumption. To test the validity of this assumption we turned again to the facts as revealed by business statistics. We found, first, that new plant and equipment are constructed in any large way only when consumptive demand is *simultaneously* expanding, and, second, that the rate of growth of new plant and equipment over a period of years is adjusted to the rate of increase of consumptive demand rather than to the volume of money savings that may happen to be available for investment purposes.

It follows from this analysis that the amount of money savings as compared with the amount of consumptive expenditures is a matter of fundamental importance; and since the percentage of the total income that will be devoted to consumptive purposes depends upon the way in which the income of society is divided among the various groups, the distribution of income presents a problem of the utmost importance.

It was stated early in this discussion that the economic system is an evolving organism. The analysis which we have just been making illustrates the influence of changing conditions upon economic interpretation. In former times when incomes were low and few people had large accumulations there was almost always a shortage of investment funds. But in consequence of the higher levels of income now prevailing and its increasing concentration the balance has tipped the other way. Instead of a shortage of funds for investment we now tend to have an excess.

I may add that in the final division of our investigation we have discussed several alternative means of accomplishing the desired end and have indicated the methods by which we think economic progress is most likely to be achieved. Space does not here permit even so much as a recapitulation of this phase of our analysis.

BODY ANATOMIC AND BODY POLITIC

By Dr. E. V. COWDRY
PROFESSOR OF CYTOLOGY, WASHINGTON UNIVERSITY

I

ARE methods of regulation within the human body of any interest to those responsible for regulation within the nation? There is nothing new about this question. It has been often asked and answered by philosophers. Economists have usually sidestepped it, deterred by the fact that the body anatomic and the body politic are not the same, so that comparisons between the two are of doubtful value and may even be misleading. One of our physiologists, Cannon of Harvard, has, however, bravely entered the lists.

The concept of organic evolution deals with the succession of animals and plants on the globe and their mutual relations up to the human body politic. It has been the cause of many a wordy battle between scientists and churchmen. The opposition of the latter and the earnest and sincere loud-speakers on both sides have proved most stimulating, with the result that all educated people to-day know and appreciate the fact that evolution has taken place, though they may differ in their opinion as to the methods employed by nature.

The cell theory, of almost equal importance, according to which all plants and animals are made up of very small individual living units, miscalled cells, is now universally acknowledged to be true in fact. It is, however, almost unknown to the laity and for an interesting reason. Theodor Schwann, a good Catholic, presented the manuscript of his classic paper to the Bishop of Malines for approval before it was published in 1839. Criticism was thus officially disarmed at the outset. The stimulus of resistance was lacking. No heated discussions took place in public. Consequently the public generally has not grasped the significance of this far-reaching generalization.

II

An accurate census of individual cells in the body anatomic has never been made. The estimated number is, however, about 26 million million. The largest is the egg. If a series of human eggs were placed in line side by side, about 250 of them could be fitted in, in a distance of one inch. If they were very dense or strongly pigmented, and the lighting were just right it is possible that single human eggs would be barely visible to the naked eye. But they are neither. All the other cells are of microscopic dimensions. We visualize them as tiny, jelly-like masses of variable consistency, diverse form and usually colorless. All respond to stimuli, but they do so differently, depending upon their habits. They have less freedom and are more "bound upon the wheel" than members of the body politic. The bonds consist of heredity and of physical and social environments.

With certain reservations, the comparison can be carried further. Cells like humans pass through periods of youth, maturity and old age. Each must breathe, have food and drink as well as suitable surroundings. They specialize by learning to do less and less, better and better. The life-span of some is measured in years and of others in days. Thousands are dying every hour, but the body anatomic endures for the traditional threescore years and ten unless the regulation breaks down.

Let us compare some types of cells with the millions of individuals which constitute a fairly self-contained nation for which internal social regulation is a pri-

mary problem. The muscle cells may be likened to the manual laborers. They make up a very large part of our body as the laborers do that of the body politic. The gland cells may be looked upon as manufacturers; since, from crude materials, they make special products of use in the community. The nerve cells are the oldest and wisest. They constitute the ruling class and have special means of gathering information; domestic, from within the community, and foreign, from the outside world. The fat cells have something in common with bankers, since they store potential, not actual, energy and give it up reluctantly on demand. Order is enforced by the leucocytes or policemen. These cells attend to many matters, including the arrest of bacteria that may invade the body. The highways (large arteries) and byways (capillaries) are regularly patrolled by them. Usually they remain in the streets (blood vessels) but, in search for offenders, no part of the body anatomic is immune from entry.

With increase in cellular specialization the birth rate goes down. For example, some cells in the manufacturing group can, by division, produce more cells of the same sort. Not so, the high and mighty nerve cells. As soon as they have learned their duties and have established social contacts with others that they consider on an equal footing, they lose all ability to reproduce their kind. Only by a local social revolution in their class—a neuroma or tumor of nerve cells—can fruitfulness be maintained and then it is of a perverted kind, pregnant with danger for the body anatomic.

Obviously, the body is more than a mere collection of millions of individuals. It has a personality. About this feature there have been many tiresome arguments. Briefly stated, personality results from the memory of, and physical changes caused by, adjustments—both external and internal—between the body and the outside world and between the individual cells that make up the body. So, too, the personality of the body politic is more than the sum of the qualities of all the people in it. Its personality, exemplified by Uncle Sam and John Bull, is conditioned by the memory of, and material changes caused by, external and internal adjustments. The first results from contact with other nations and with the forces of nature and the second from association of individuals and classes within it. Obviously, heredity is also a potent factor in conditioning personality, whether it be of the body anatomic or politic.

III

By experience, through millions of years, nature has evolved interesting methods for regulating and integrating the hordes of individual living cells which make up the human body.

Food taken in from the digestive tract is distributed by the cardiovascular system of transportation to each and every kind of cell, be it noted, not in equal amounts, but according with its needs when working and resting.

Work is demanded from a great many more cells than in ordinary times are needed for the maintenance of the community. Removal of $\frac{9}{10}$ of the adrenal cortex is not incompatible with life. Similarly, it is said that $\frac{1}{2}$ of our lungs, $\frac{2}{3}$ of our kidneys, $\frac{3}{4}$ of our liver and $\frac{4}{5}$ of our thyroid and pancreas can be dispensed with. It is difficult to think of an organ of the body not over-supplied with cells.

The primary division of labor is between classes of cells that have specialized in different directions. In each occupation the work required is assigned to the individuals having in mind first the needs of the body as a whole and second those of the individual. Unemployment, if prolonged, is followed by wasting and death. However, large classes of cells live on the community, with regular duties so light as to be little known and almost unappreciated, but they are ready to help in emergencies. We think at once of the so-called fibroblasts that take part

in the formation of fibers which hold things together and are essential in the architecture of the body anatomic. These cells, as they exist under the adult epidermis amid the proper number of connective tissue fibers, have not much to do. For them to go on rapidly forming still more fibers would be a calamity. In case the skin is cut through, they display very gratifying activity and the fibers, that they help to make, draw the edges together. Muscle (and perhaps nerve) cells exhibit a high standard of service. Though quiescent for considerable periods, when called into action they do their level best. In the words of the physiologist, an adequate stimulus leads to maximum work. Increasing the stimulus beyond this point does not lead them to perform more effectively. When the stimulus is decreased they do not respond. This is the "all or none law" of labor.

The excess of willing hands in every basic occupation is termed the physiological reserve. Engineers have learned, likewise by experience, that they must always provide a factor of safety. They must build a bridge capable of sustaining a heavier load than it is expected to carry, a boiler that will not burst when subjected to a pressure higher than that necessary to supply the head of steam required, and so on. With respect to work, the body anatomic is wiser than the body politic. The task is accomplished by multiplication of single workers. Never is the risk incurred of disrupting established conditions by the sudden introduction of some new invention permitting one to do the work of many.

But aids for effective work are provided in abundance. The use of hinges, levers and plenty of lubrication was discovered long, long ago. Lime is employed in building bone, as in making concrete. Organic material is distributed as needed in bone. And we recall how the Egyptians, in biblical times and even to-day, put straw in bricks. Rubber is an important article of commerce. Elastic tissue, or vital rubber, is employed in varying amounts in the construction of most parts of the body anatomic; but in largest amounts in the vascular system which unifies and integrates.

When human beings in the body politic grow old they tend to be neglected, except in China and some other Oriental lands, where they are highly venerated. With us, they are expected to cease work without remonstrance and to await the end philosophically. To the cry, "I want still to be of some use," a deaf ear is usually turned. Neglect of the aged is an indictment of modern civilization. It is our duty to profit from the many ways that they can serve. Nature is inexorable, but it is not unkind. Many aged and dead cells are not only utilized but are given positions of great importance. Firmly bound together in a dense layer on the surface of the skin, dead epidermal cells act as a shield and protect the living cells within. Without this thin, delicate and flexible covering the body anatomic could not endure. Nature has arranged for another category of dead cells to carry life-giving oxygen to all the rest. Until they die, red blood cells perform no useful service. Their entire life is shaped so that they may serve after death. By dying as they do their corpses acquire physical and chemical properties which lead to the absorption of oxygen in the lungs and the subsequent liberation of oxygen throughout the body.

Rest is mandatory, for without it the working billions of cells would soon fail. But the time allotted to recuperation differs with the occupation. Laziness is not permitted. Mischief makes for idle hands to do. To give freedom, after a standardized eight- or ten-hour working day, is not the way of nature. The well-being of the body anatomic is the main and only consideration. For some rest comes, or should come, with darkness. We think at once of the cells of the eye, of the skeletal muscle cells by which we

move and of the nerve cells that direct them. These, and many others, are the day laborers. The system of transportation for the distribution of crude materials and finished products is never allowed to lag. Cardiac muscle cells rest for about 15 hours in the 24; but they snatch their rest in very brief periods, as ordered. The muscles of respiration must likewise be content with momentary relaxation. Removal of waste, as performed by the kidneys, depends to some extent upon the intake. With them, there is evidence that some groups of cells (the glomeruli) operate in shifts —a method frequently adopted for individuals making up the body politic.

A suitable environment in which to work and rest is as necessary for cells as for individuals. Sudden and radical changes must be avoided. Responsibility rests on government in the body anatomic, and on the cells themselves, as classes among which the labor is divided. It is the duty of government to supply through the system of transportation (blood stream) vital necessities and optimum amounts of crude materials needed in the several occupations. Special methods are employed to regulate the quality of the supply so that it shall be uniform and not subject to dangerous fluctuation. It is the duty of the groups of cells, relying on this help, to continue their labors without interruption. Since their functions are diverse, comprising all those necessary to the welfare of the community, and because individuals in like occupation are naturally associated, there is superposed upon the basic, unifying and stabilizing influence of wide distribution of vital necessities and materials a local diversity. Thus, the local environment of the manual laborers grouped in the muscles differs from that of the manufacturers grouped in the thyroid gland. Each, by requiring rather different materials, in addition to vital necessities, by working in a different way and by developing distinctive associations makes inevitably a different environment. Farm laborers create for themselves different surroundings, both physical and social, from those inevitable in an industrial center. Take the nerve cells. They occupy two strata in society within the body anatomic. One is lower, mingles more intimately with the general population and behaves more automatically; while the other is higher, directs more or less consciously, and, holding itself aloof from the common herd, occupies a sheltered and privileged position in the brain and spinal cord guarded by strong bony walls. A serious disturbance may arise, either from deficiency or surplus, in the government-run system of supply or from a change in the local environments occasioned by failure of groups of cells to provide stability therein by not attending to their duties.

IV

It will be observed that the cells of the human body are aquatic, since they live as small groups or communities in a watery environment regulated by the blood stream and their own individual efforts. The human beings of the body politic, on the other hand, are outwardly terrestrial and live on dry land. But, thanks to Darwin and the others, encouraged and strengthened by spirited opposition to their views, it is now generally accepted that we humans have developed from animals who were inhabitants of the ocean. All these ages we have carried parts of the watery environment with us. Those who by chance read these words do so by looking through thin films of salt water supplied by the lachrymal glands. If these vestiges of the original watery environment of the body politic were allowed to dry up blindness would ensue. They may throw the book away with a sigh of relief, in which event they find momentary refreshment by increased absorption of atmospheric oxygen, again through a thin layer of salt water lining their lungs. Later on, they may listen with approval to criticisms of

the wild ideas expressed in this paper; but they can do so only by using little bodies of salt water which constitute essential parts of their inner ears. Our forgotten ancestors learned to see and to breathe and to hear in salt water and we must perforce do the same, so that we are at least partly aquatic. To express it differently, the surfaces of our bodies in contact with air are all coated with dead cells (skin, hair and finger nails). The surfaces, external and internal, made up of living cells (cornea of eye, inner ear, lungs, digestive, urinary and reproductive tracts) are all wet, *i.e.*, aquatic.

Physiologists are very positive about the importance of the fluid cellular environment. Consideration of the totality of circulating fluids in the body led Claude Bernard in 1878 to make the statement that "all vital mechanisms, however varied they may be, have but one object, that of preserving constant conditions of life in the internal environment." This is one of the truly great conceptions in biology, though the constancy is not so rigid as he thought. It is subject to slight but significant changes in pregnancy, for example. In the analysis of the mechanisms, Cannon and his associates have taken a leading part. Many of the regulated properties, such as temperature, acid-base equilibrium and pressure, are without evident parallel in the body politic. It is the control of deficiency and surplus that is instructive. Freedom from sudden change in the amounts of substances in the internal fluid environments is provided by regulation of production, by storage, by elimination of surplus and by efficient distribution. The body politic has quite independently discovered the same methods. The trouble is that it fails to use them properly.

V

We are concerned with production in so far as it involves increase or decrease in materials in circulation. This may happen from over-eating, under-eating or from disturbances in assimilation or excretion. Normally it is not brought about by failure to regulate domestic production by glands and other tissues. In the body politic conditions are somewhat reversed. Imports are frowned upon, not because by their addition surpluses are created, but because they are unwelcome to certain classes in the community. In other words, the well-being of a part is placed before that of the whole—a condition rare indeed in the body anatomic. But it is chiefly in the regulation of production of crude and manufactured materials that the body politic fails. Instead of humanizing the Bureau of Standards and of developing, as nature has done in the body anatomic, mechanisms by which slight increases or decreases in the materials in circulation are quickly detected and the activity of the cell groups responsible is promptly adjusted, we have obeyed the command of Lao Tzu, "let matters take their own course and do not interfere," for we prized our own liberty and wished also to guard that of others. Nature, on the other hand, does not recognize individual rights and is far from being sentimental. Confronted by surpluses the administration has courageously attempted to reduce production, but in doing so the aid extended to the producers by artificial increase in price through curtailment of output has worked a serious hardship on the rest of the body politic.

Another way to care for at least part of the surplus is by storage. This setting aside until needed is an act of survival value. The body anatomic stores part of the excess of ingested foods against the time when they may be required. But storage is not resorted to until the amount in the circulation, being distributed effectively to all parts, is more than enough. Thus, fat is stored chiefly in the subcutaneous tissue, carbohydrate in the muscles and liver, protein in the liver, calcium in the bones and various other substances in appropriate locations. The

chance of failure to find water is not so great. Therefore water is stored only to a small degree. Oxygen, another prime essential, is present everywhere in the air. The contingency of having to do without it does not have to be faced. Consequently no arrangements are made for storage. When more materials are needed by the cells, which for some reason are called upon to work harder, they take more from the blood stream. To compensate for this loss, increased amounts are simply released from storage and circulated without the formality of requisitions in triplicate to be approved by a long line of officials. The release is so prompt that a serious deficiency in the blood stream is prevented and the release is so quickly inhibited at the right moment, that a marked surplus is not created as the unusual demand is satisfied.

The body politic may also horde imports for use when required. Surpluses in domestic production, curbed as we have seen in the body anatomic, constitute a serious difficulty, mainly on account of the inadequacy of the system of transportation. To store, as a remedy for local surplus, before the legitimate demands of the entire body politic are met, nature would call bad management. It is worse to use the device of storage to serve a particular group concerned in the production of a special commodity and by withholding it from the majority to make the majority pay an increased price for something that they must have. True, the idea was to increase the purchasing power of those not favored by the experiment so that they would not suffer unduly. To have both effects produced at the same time was more than could be expected and did not happen. The body anatomic would never interfere so radically.

Elimination of actual surplus is practiced without compunction by the body anatomic. Products of digestion not needed to maintain the all-important constancy in properties of the blood stream and not used for storage (because to push storage to an extreme would be unwise) are simply eliminated by the kidneys. The body politic has been known to act hastily in the disposal of apparent surpluses. The word "apparent" is used, because a very noticeable local surplus may exist in the absence of an actual surplus in the nation considered as a whole. It may even occur in one part of the country while there is a serious deficiency elsewhere. If our body politic had possessed a centralized, properly controlled and operated system of distribution or transportation, comparable to the cardio-vascular system, local surpluses would be as rare as in the body anatomic and we should not have to explain the burning of grain in Kansas, urgently demanded in industrial areas; the allowing of oranges to rot in Florida, which could be used to great advantage elsewhere; and the letting of coal heap up at the mine heads, while people suffer from the cold in other parts of the country. Evidently transportation of essentials in the body politic, as in the body anatomic, must be maintained and directed for the benefit of all at the expense of all, each paying according to his ability.

Electricity is a new plaything and money-getter in the eyes of the body politic. We are just beginning to realize its uses. Nature is a long way ahead. From the beginning of life on the earth living cells have been constructed as electrical engines. No cell in our body could function, nor even exist, if electrical changes in it were shut off. Rapid integration by the nervous system (telephone and telegraphic systems) would cease. The muscles (heavy industries) would no longer operate. All glands (factories) would stop. Death would be complete and in this case instantaneous for all cells in the body. Life-giving power must be made available to all (not simply to a privileged few) in the form

of an uninterrupted supply of necessary materials via the blood stream. The declaration of policy of the Tennessee Valley Authority, that " . . . the interest of the public in the widest possible use of power is superior to any private interest, with the result that in case of conflict, the public interest must prevail," is sound biologically.

VI

The human organism can well be admired as the noblest of creations, but it is not a perfect mechanism. We have limited ourselves to a consideration of an average, healthy specimen. Regulation of production in the body anatomic sometimes fails. For the manufacturers in the thyroid to produce and throw on the market more than is needed causes Graves' disease, sometimes termed exophthalmic goiter because the eyes protrude. The unfortunate individuals are geared up to a higher rate of activity than they can stand. Conversely, when the product is available in insufficient quantities, there is marked lethargy. Many other examples of too much and too little activity might be cited.

That about one in every four humans dies as a result of some form of cardiovascular disease should be an object lesson to physicians and statesmen alike. It will be said that death of the body politic through failure of the corresponding transportation system does not take place, for the human race flows on. But for some reason, the bodies politic of ancient Rome, of the Incas, Mayas, Czaristic Russia and a score of others have disappeared, despite the survival of descendants of individuals. Devastating diseases and changes in climate, rendering life in the occupied areas much more difficult, have been prominently mentioned as factors. In order that the race may continue individual cells of the bodies anatomic, the eggs must also survive its death and leave descendants. When the circulation fails and consciousness is lost the individual is pronounced dead. This is true as far as the individual is concerned, but some of the cells of the body continue to live for varying periods. The heart has been made to start beating again in executed criminals. Nerves remain alive, for by their stimulation muscular contraction is produced. Lewis and McCoy of Hopkins have found that in animals left at room temperature some kinds of cells may survive for 120 hours. If given a fair chance many of them are able to continue living. All that is required is to remove them quickly from the dead (!) body and place them in specially prepared fluids. There is good reason to believe the cells cultivated in this way outside the body will continue to multiply and produce their kind as long as the fluid environment is suitable and the excess growth is removed. The most obvious difference between death of the body anatomic and failure of the body politic to survive is the regularity and inevitableness of death in the former, whereas the particular social organization that characterizes the latter may last for a longer or shorter time, depending on circumstances. The disintegration and decay of human beings and of nations is brought about in many ways.

Ranking perhaps next to failure of the transportation system is antisocial behavior of special groups. One in every ten of us dies of cancer. The nature of cancer is shrouded in mystery and its real remedy still unknown. Nevertheless, there is an almost worn-out simile. Often, when the body anatomic attains maturity, rarely in youth, some cells display a dangerous irresponsibility to the welfare of the whole. They shake off community control, pilfer the food of others, invade their homes and increase in number without restraint. Particularly serious it is if this happens in some location hidden deeply within the body. When the malignant cells force their way into the blood stream (or lymphatics) and are distributed throughout the body the outlook becomes hopeless.

In the body politic a process analogous,

though of course only superficially so, may occur. It is not so likely to be manifested in a young and vigorous nation busy expanding geographically and in other ways as in a more mature and settled community in which individuals have time to harp upon their troubles. Here, also, irresponsibility may develop and antisocial tendencies, likewise an overpowering urge to be done with the particular sort of national control that irks. The malcontents at first create merely a local disturbance in the submerged part of society and are little appreciated by the body politic. They do not take time to increase in number by multiplication, as the cells do. Instead, they try to persuade others to join them, generally, without much success, despite the appeal "take from those that have and give to those that have not." But their strategy is not very different from that of the cancer cells. If they can gain control of the system of transportation and use it freely to spread their doctrines a violent upheaval is almost inevitable.

Fortunately much may be done to save the day in the body anatomic as well as in the body politic by early recognition of what is taking place. It is to be observed that both the cancerous change, and the anarchistic one, frequently follow some kind of repeated irritation or injury. Neither cell nor individual can, as a rule, be accused of embarking upon this mad career without provocation.

VII

Such breakdowns emphasize further the importance of stability of environment for the cells in the body anatomic and for the people in the body politic. The price paid in the body anatomic is loss of freedom. It is in no sense a democracy, nor even a kingdom. The individual cells live and die for the benefit of the whole state, and most of them must stay put in the position to which they have been called. Existence, except as part of the state, is ordinarily out of the question. Nature has been careful to treat all cells of the same class equally with respect to food, labor demanded and rest as well as living quarters. This equality within a given class is an object lesson for the body politic. On the other hand, class distinctions are maintained rigidly and without exception, for without them specialization and division of labor could not be provided. Evidently class distinctions are equally essential in the architecture of the body politic.

The integrity of the body anatomic is also paid for by regulation of reproduction of individuals. When the optimum number in each class is reached birth control is enforced. And, again, this additional class distinction is imposed for the benefit of the body as a whole. The principle adopted is that in each class reproduction shall compensate for inequality in death rate. The body anatomic is the product of long years of evolution, while the body politic is a new creation. Not until we get over the relatively brief phase of geographic expansion and the populations of the various nations are forced into equilibrium, with but little increase or decrease in number, can we look for much in the way of real social democracy. It is possible that those nations will lead, in respect to the welfare of their citizens, if not in material power and glory, that attain internal equilibrium first. Sweden, for instance, is to be congratulated on the beginning she has made.

BASAL FACTS IN THE HISTORY OF MATHEMATICS

By Professor G. A. MILLER
DEPARTMENT OF MATHEMATICS, UNIVERSITY OF ILLINOIS

UNDER the entry "algebra" in the second edition (1934) of Webster's "New International Dictionary" there appears the following striking statement, which relates to the experiences of a large number of educated people: "The essential difference between arithmetic and algebra is that the former deals with concrete quantities while the latter deals with symbols whose values may be any out of a given number field." In view of this quotation from a work which is now widely used in our schools it may be desirable to emphasize the fact that it is impossible to prove that arithmetic now deals relatively more with concrete quantities than algebra. For instance, the ordinary multiplication tables deal entirely with abstract numbers and the first table in the ancient Egyptian work entitled "Rhind Mathematical Papyrus" (about 1700 B. C.) deals also entirely with abstract numbers. One of the basal facts of mathematical history is that the mathematical literature which has been preserved from the past ages is relatively about as abstract as that which is now being written.

There is no clear line of demarcation between arithmetic and algebra. Various developments are sometimes classed with arithmetic, while at other times the same developments are classed with algebra. For instance, the theory of determinants has sometimes been treated under the heading of arithmetic, while it is now more commonly regarded as belonging to algebra. The theory of equations is usually regarded as a characteristic subject of algebra, and the number system of algebra is commonly regarded as more general than that of arithmetic. In fact, there is an evident tendency towards generalization as one advances in mathematics, but there is no definite evidence of a tendency towards dealing with a relatively large number of abstract notions in modern mathematics than in the extant older developments of our subject. In both pure and applied mathematics there are many evidences of progress, but the relative extent of these developments does not seem to have changed much during historic times. It has recently been pointed out by O. Neugebauer, Copenhagen, Denmark, that even the ancient Babylonians used negative numbers, but they did not understand the theory of these numbers in the modern sense.

These recent discoveries relating to negative numbers imply that these numbers were gradually developed during a period of more than three thousand years before a satisfactory theory thereof was published. The fact that their use in applied mathematics still sometimes presents difficulties can be seen from the following striking quotation from the writings of an eminent scientist and winner of the Nobel prize (1921): "I have tried, in other fields, to show the incredible confusions, of which the whole world is now one seething example, that have followed from the invention by the Hindu mathematicians of negative quantities, and their justification from their analogy to debts."[1] No such confusions exist now in pure mathematics as regards the use of negative numbers, but when these numbers were finally adopted it became necessary for the pure mathe-

[1] F. Soddy, "The Interpretation of the Atom," preface, 1932.

maticians to abandon some views of long standing, including the view that the ratio of a larger number to a smaller number always exceeds the ratio of a smaller number to a larger, since $3/2 = -3/-2$ and 3 is larger than 2 while -3 is smaller than -2.

A basal fact in the history of mathematics was expressed by F. Klein (1849–1925) in the following words: "Think of it; one of the greatest advances in mathematics, the introduction of negative numbers and of operating with them, was not created by the conscious logical reflection of an individual. On the contrary, its slow organic growth developed as a result of intensive occupation with things, so that it almost seems as though men had learned from the letters."[2] The utility of some mathematical advances sometimes forced these advances on the mathematical public before a satisfactory theory for these advances had been developed. The extension of the number concept so as to include ordinary complex numbers may also be said to have forced itself on the mathematical public long before a satisfactory theory of these numbers had been published. One of the almost mystical elements of the development of mathematics, which was unobserved for a long time, is that when an unknown becomes involved in the form of an algebraic equation of degree n it associates with itself $n-1$ other unknowns which may have some quite different properties but for the solution of this equation are equivalent to the given unknown.

It should be emphasized that the history of mathematics in so far as it is based on written evidences extends over a period of only about six thousand years and that very little is known in regard to the mathematics of the first thousand years of this period. Mathematical chronological tables which extend to earlier periods are based on indirect evidences and hence they are of doubtful historical value. The main fact in this connection is that the earliest mathematics which is extant is somewhat advanced. In the Babylonian countries it includes at least partial solutions of the quadratic equation by completing the square just as is done in modern times, and the partial solutions of equations of higher degrees, including the sixth, by methods which differ from those now commonly used. In Egypt it includes the determination of the volume of the frustum of a square pyramid by a method which is still in use. Hence it results that a considerable part of the early developments of mathematics will probably never be accessible to the student of the history of our subject.

A somewhat curious fact is that the reliable history of the most ancient mathematics is now the most recent mathematical history and relates mainly to Babylonian and Egyptian mathematics. The most extensive data relating to ancient Babylonian mathematics were published in 1935 under the title "Mathematische Keilschrift-Texte" and appeared as volume 3, Abteilung A, of the periodical called *Quellen und Studien zur Geschichte der Mathematik, Astronomie und Physik*, which was started in 1930 and appears irregularly. Considerable has been published in regard to the ancient Chinese mathematics and the ancient Hindu mathematics, but very little of this material is now regarded as reliable by the critical mathematical historians. Much of the history of the mathematics of the ancient Greeks is also unreliable and has been greatly modified in recent years. The works of Euclid, Archimedes and Apollonius exhibit, however, very great advances beyond those of the earlier writers on our subject.

A characteristic feature of the mathematics of the ancient Babylonians is that

[2] F. Klein, "Elementary Mathematics from an Advanced Standpoint," pages 25 and 27, 1932. Translated into English by E. R. Hedrick and C. A. Noble.

they developed a positional arithmetic to the base 60 in which two numbers which differ from each other only by the fact that one is a power of 60 times the other are represented by the same symbols. By means of this notation they could treat fractions in exactly the same way as integers when they are combined according to the fundamental operations of arithmetic. Their method was similar to our modern method of using decimal fractions, with the exception that they did not use a symbol corresponding to our decimal point and hence they did not employ either initial or terminal zeros. This system of numerical notation is unique in the history of mathematics and it is of great interest because it points to the possibility of using numbers merely as representatives of geometric series with a common ratio which is equal to the base of the number system. By this method each such progression is represented by the same numerical notation and each such notation represents any one of the numbers in the same series. This is a very remarkable system of numerical notation.

These recent discoveries relating to the ancient Babylonian mathematics exhibit the fact that general histories of mathematics are apt to be soon out of date along certain lines and hence they should be used only in connection with the recent periodical literature dealing with the same subjects. There probably never before was a time when such important modifications as regards mathematical history became necessary in such a brief period of time as during the last two or three decades. This does not imply that former general histories on our subject have become useless, but that they should be used cautiously and in the light of where recent progress has been made along the line of mathematical history. Unfortunately, many of the general histories on our subject failed to embody various recent advances at the time when they were published. This is especially true of most of those which appeared in the English language, including American publications. Even a decade ago no one knew that the ancient Babylonians had made important advances in algebra.

The ancient Greeks seem to have been the first to take an interest in the history of mathematics. As far as we know now the earlier writers regarded mathematics as an impersonal subject for which no individual deserved special credit but which was common property just as the air we breathe. The idea of discovering mathematical truths to be transmitted to all future generations as an enrichment of their intellectual heritage does not seem to have engaged the attention of the predecessors of the ancient Greeks. Even the "Elements" of Euclid contain no historical references, and this example was followed by many later writers. On the contrary, Archimedes says near the opening of the first book of his work on the sphere and cylinder, in speaking of Eudoxus with respect to the volume of a pyramid, "For these properties also were naturally inherent in the figures all along, yet they were in fact unknown to all the many able geometers who lived before Eudoxus, and had not been observed by any one."

Mathematics involves thousands of theorems and methods which have not been traced to their origins in the extant literature. General mathematical histories therefore deal with selected sets of results which are supposed to be of special interest. The large German mathematical encyclopedia, which began to appear in 1898 and was announced as completed in 1935, aimed to include the historical development of the mathematical methods since the beginning of the nineteenth century. It also aimed to devote the last of its seven proposed volumes to history, philosophy and didactics, but unfortunately this volume was abandoned, and hence we do not as

yet possess an encyclopedic treatment of these subjects on a large scale. The fact to be emphasized in this connection is that in view of the enormous extent of the available material the general histories of mathematics have restricted their attention to a comparatively small number of facts. A complete history of mathematics is impossible not only on account of the serious gaps in our knowledge but also on account of its extent.

Elementary mathematics has become a kind of thought currency which is used for its convenience by many who do not consider its real nature, just as in financial transactions people use the currency of the land without always considering the basic principles which give value to it. The history of mathematics can not be fully understood without bearing in mind that there is a wide difference between learning to use mathematics in the solution of problems and mastering the fundamental principles of the subject. The pre-Grecian mathematics which is extant consists almost entirely of the solutions of particular problems, and it seems very unlikely that many of those who learned how to solve these problems interested themselves in securing an insight into the reasons why correct results were obtained in the given manner. An important source of mathematical progress is that many rules used to solve special problems were later seen to be much more general than these special problems indicated.

Another analogy between business and mathematics is that the literal constants in formulas correspond to the blanks left vacant in business forms. The numerical values of these constants have to be supplied before the given formulas apply to individual cases just as the blanks in a business form have to be filled in before it is useful in an individual case. Historically it is of great interest to note that mathematics did not reach this blank form stage until about the time of F. Vieta (1540–1603). The formulas which became possible by the development of the algebraic notation effected the same kinds of economy in mathematical work as are effected by the forms with blank spaces in business. The use of the former as well as that of the latter seems to have increased rapidly in recent times. The observations which apply to the general algebraic equations may be compared with the observations which apply to all deed forms to property before the blank spaces have been filled in so as to individualize these deeds.

From the standpoint of accuracy the situation of the history of mathematics in our schools is almost pathetic. This subject is now most commonly taught where the facilities to become acquainted with recent advances in it are meager and by means of text-books which failed to embody many of the advances at the time of publication. According to a recent article[3] 42 per cent. of the teachers colleges and normal schools in the United States of America offered then courses in the history of mathematics, while only about 26 per cent. of the colleges and universities offered such courses. What is more important in this connection was recently stated by President J. B. Conant, of Harvard University, in the following words: "If our young men and young women are to have an understanding appreciation of the spiritual values of the civilization which they inherit, they must be given an account of the historical development of our knowledge and of our philosophy. The history of science, the history of ideas, the history of scholarship and the history of universities should now be occupying the attention of many instead of a few. A discussion of these subjects with the proper emphasis on their relation to social and political history might well form an important part of a liberal education, but

[3] A. W. Richeson, "Scripta Mathematica," Vol. 2 (1933–4), page 16. Very meager prerequisites are commonly noted for the students who take these courses, as is noted in this article.

to find satisfactory teachers for such subjects is now almost impossible. Until we have an adequate survey of our intellectual history we can not expect the world at large to understand the importance of the scholar's contribution to civilization."[4]

The fact that it is now almost impossible to find satisfactory teachers of such subjects should be especially emphasized in this connection. It is equally true that it is now almost impossible to find satisfactory text-books along this line. Hence in most cases we find the combination of an unsatisfactory teacher with an unsatisfactory text-book and naturally the result is also unsatisfactory. The most hopeful thing along this line is that students continue to manifest an interest in this subject wherever they are not too strongly impressed with the idea that all their available time is needed to become sufficiently familiar with some narrow field to secure therein the Ph.D. degree. The example of the new Ph.D. degree at Harvard University may exert a wholesome influence on the other universities of our land. At least it is desirable to emphasize the need of becoming acquainted with the many advances which appeared in the periodical literature of recent years and the need of supplementing the text-books by means of these advances.

Mathematics is unbounded, undivided and undefined. Among the mathematical ideas those of number and geometric figure have supplemented each other since the times of the oldest records. The ideas of equation and function appear also in the oldest extant mathematical literature. The latter appears in the rules for the areas of triangles and rectangles in terms of their sides and altitude, and the area of a circle in terms of its diameter. The idea of the limit of an infinite geometric series whose common ratio is less than unity appears in the works of Aristotle and Archimedes, and the explicit formulations of the concepts of function and group appear towards the close of the seventeenth and eighteenth centuries, respectively. These six fundamental mathematical notions underlie most of the later mathematical developments. The idea of limit assumed an especially prominent place when the subject of the calculus began to be vigorously developed near the beginning of the eighteenth century. The first text-book on this subject appeared in 1696 under the title "Analyse des infiniment petits," by G. F. A. de l'Hospital.

Many of the advances in the history of mathematics as well as in mathematics itself have been due to the repeated correction of errors. In a recent book by the well-known Belgian mathematician, M. Lecat, entitled "Erreurs des Mathématiciens des origines à nos jours," 1935, the following names are included among those who committed errors in their publications: N. H. Abel, A. L. Cauchy, A. Cayley, R. Descartes, L. Euler, K. F. Gauss, J. L. Lagrange, S. Lie, I. Newton and H. Poincaré. All these names appear also in this work among those who corrected errors in a public manner. This implies that some of the most eminent mathematicians of all times have taken part not only in the removal of errors which appear in the published literature but have also not always been sufficiently cautious to avoid the committing of errors in their own work.

The lasting reputation of a mathematician is based upon a kind of residue after his harmful publications are subtracted from those which have proved to be useful. There is a great difference as regards the discredit due to erroneous publications. When these relate to the newer fields where advances are extremely difficult, very useful work has often been done by those who proceeded without awaiting the building of safe

[4] "A New Ph.D. Degree at Harvard University," SCHOOL AND SOCIETY, 41: 639, 1935. This degree is to be given for work in the history of science and learning.

roads. For instance, in the work noted in the preceding paragraph it is stated, page IX, that the greater part of the researches on the calculus of variations before 1870 involves methods which are inexact or insufficient. Similarly, the early lists of groups were often very incomplete and involve faulty methods. Such errors are commonly regarded with a great deal of tolerance. Similar errors in the recent literature on these subjects would, however, appear as intolerable as the inclusion of the name of Gilbert in the following list: Galileo, Kepler, Gilbert, Napier, Fermat, Descartes, Pascal, Huygens, Newton and Leibniz; and the statement that John Farrar (1779–1853) "did much for elementary mathematics in this country through his translations (1818–1825) of the works of Euler, Lacroix, Legendre and Bézont, and through his publication of a number of textbooks."[5]

To understand the shifting of interests in the development of mathematics it is necessary to bear in mind that there are fashions in the mathematical world as well as elsewhere. To have a work accepted as correct and novel requires only that it fulfils certain conditions which can usually be easily applied to it, but if it is to receive special attention and to secure for its author special recognition it must meet also external situations which are frequently biased and unfair. There have been many so-called schools of mathematicians of great influence in which undue attention was paid to those who cultivated its temporary fads. In our own country these centers of undue influence have been less pronounced than in Europe and have shifted from time to time as its leaders either died or abandoned their positions. Fortunately, there are, however, also subjects, such as differential equations, in which the interest is more lasting and work of high merit has usually been recognized independently of its source. Meteoric reputations in mathematics have not been very common in the supposedly well-informed circles.

[5] D. E. Smith and J. Ginsburg, "A History of Mathematics in America before 1900," pages 13 and 96.

FIFTY YEARS OF INDUSTRIAL ALUMINUM

By Dr. HARRY N. HOLMES

PROFESSOR AND HEAD OF THE DEPARTMENT OF CHEMISTRY, OBERLIN COLLEGE

ALTHOUGH aluminum was first isolated in 1825 by Oersted of Denmark, the entire world production prior to 1889 was but little more than 100 tons, according to Packard in Census Bulletin No. 79.

It is not too much to assert that when young Charles Martin Hall, just fifty years ago this February 23d, discovered the present commercial process of producing cheap aluminum he really gave the industrial world this extraordinarily useful metal. The infant industry, squawking feebly in its swaddling clothes in the Smallman Street factory, Pittsburgh, grew rapidly from a daily production of 50 pounds at the end of 1888 to an annual world production of 600,000,000 pounds.

Equally sensational has been the price range from the impossible $160 or more per pound due to Wöhler, the $27 secured by Deville in 1856 and his final record low of $12 per pound, and the $6 due to Castner's work in 1886 to the present 20 cents per pound due to the invention of Hall and the technical enterprise of his company.

It is remarkable that the most common metal in the earth's crust was so long delayed in its arrival on the industrial stage. Although every claybank is an aluminum mine, as Deville said, the great chemical stability of aluminum oxide was a hurdle too high for the most agile scientist to leap—until 1825.

Then Oersted, famed for his fundamental research in electricity, freed the metal from chlorine in anhydrous aluminum chloride by heating with the extremely active metal potassium:

$$AlCl_3 + 3K \rightarrow Al + 3KCl$$

Wöhler, at Göttingen in Germany, one of the greatest scientists of his time, learned of Oerstedt's work but failed to reproduce his results. Wöhler varied the method slightly by using potassium instead of potassium amalgam and succeeded in preparing a black powder which proved to be aluminum. So tremendous was Wöhler's prestige that, for a century, the world gave him credit for the original isolation of aluminum. Even the scholarly Deville, professor at the Sorbonne, joined in this tribute.

Poor Oersted made the mistake of publishing his research in an obscure Danish journal, where it lay buried until his countrymen, a hundred years later, forced it upon the world's attention. Chemists of the Aluminum Company of America followed the directions given in this old paper and successfully duplicated Oersted's results, something that the brilliant Wöhler failed to do. It is now in order for the world to atone for injustice by giving the Dane credit for the discovery of aluminum.

On the other hand, Wöhler deserves much credit for bringing the new metal to the attention of the world and for valuable research on the properties of aluminum.

The eminent French chemist, Deville, lowered the cost in 1854, by the simple substitution of the cheaper metal sodium for potassium in attack on a mixture of aluminum chloride and sodium chloride.

$$AlCl_3 + 3Na \rightarrow 3NaCl + Al$$

Within two years, by 1856, the price of the metal dropped from $90.00 per pound to $27.00 and by 1860 to $12.00.

Sir Humphry Davy made earlier attempts than Wöhler's to reduce the oxide and failed, as did Silliman. Berzelius,

the eminent Swedish chemist, almost succeeded in anticipating the success of Wöhler when he heated cryolite, the double fluoride of aluminum and sodium, with potassium. Unfortunately, he used an excess of potassium and got an alloy of aluminum with potassium. Had he used an excess of cryolite, Berzelius would now be given credit for presenting aluminum to science.

Henri Sainte-Claire Deville in Paris, famous French chemist, had the financial support of the Emperor Napoleon III in his efforts to take aluminum out of the aristocracy of precious metals into the democratic brotherhood of copper, zinc, lead and tin. In spite of his best efforts Deville complained that the new metal cost a little more than silver.

Where Oersted and Wöhler failed to get anything more metallic than a black powder or a pinhead-sized particle (at least until 1845) Deville made a great advance by coalescing this powder into liquid metal in a stream of hot vapors of anhydrous aluminum chloride. The sodium impurity was removed in a low-melting double chloride of sodium and aluminum.

In 1855 Deville confirmed the findings of Rose and of Percy that Greenland cryolite, a double fluoride of aluminum and sodium, could be reduced to the desired metal on heating with sodium. For good French economic reasons connected with the tariff or tax this method was discarded and the earlier method of heating anhydrous aluminum chloride with sodium was employed.

By a strange turn of the wheel of fate a certain cryolite experiment of Deville's was discussed at length in 1893 before Judge William Howard Taft, later President of the United States.

It occurred to the ingenious Frenchman that he might with advantage electrolyze cryolite melted with sodium chloride since metallic sodium would be secured by electrolytic decomposition of the common salt. The hot sodium thus formed, he hoped, would reduce the cryolite to metallic aluminum. Whatever the mechanism, he won—but not commercially. He abandoned the electrolytic process.

The first object of art made of aluminum was a rattle for the Prince Imperial, ordered by the Minister of State and the House of the Emperor. Napoleon III was said to wear with pride a helmet of aluminum. Now this exclusive royal privilege has been brought into the kitchen, where the once-precious metal caters to plebeian tastes. Although from 1860 to 1880 France was yearly producing a ton and a half of the metal its cost limited it to the trade of jeweler and goldsmith. These artisans soon learned that an alloy containing 2 per cent. copper was easier to engrave. Foucault, of pendulum fame, anticipated the plans for our giant 200-inch reflecting telescope by using a curved aluminum surface for reflecting telescopes, yet he never realized that this metal can reflect over 80 per cent. of incident ultra-violet light.

Deville felt called upon to reassure the public as to the safety of eating food with aluminum forks and spoons. He must have succeeded, for it is reported that Napoleon III at a state dinner had the most distinguished guests served on aluminum plates, while the small fry dined on plates of pure gold.

Like the will-o'-the-wisp, the goal of aluminum for common use continued to remain just out of reach until about 1885 when Castner cheapened the manufacture of sodium (hitherto necessary in producing aluminum) so radically that the cost of the latter metal was cut to \$6.00 per pound, perhaps less. And then, just as Castner was about to reap his reward, Charles Martin Hall made sodium unnecessary—and rang up the curtain on the age of aluminum.

Hall was a studious, serious-minded

son of a minister in the college town of Oberlin, Ohio. Even in his high school he was always dreaming of his great inventions for humanity—and trying them. It was most fortunate for Hall and for Oberlin College that in 1880 Frank Fanning Jewett accepted the chair of chemistry and mineralogy, bringing to the work a training equal to the best of that time. A Yale graduate, he had gone to Germany, where, in the University of Göttingen, he was one of the small group of American students who at that time specialized in chemical work under highly trained German teachers.

Most fortunately for young Hall, and for a great many people in this world, Professor Jewett took a fancy to this keen student and invited him into his private laboratory, where for years they worked together on inventions. In those days a routine course in chemistry occupied less than a year, but Hall was given years of special attention by one of the best-trained chemists in the America of that time. Careful plans of attack on aluminum, encouraged by Jewett, were laid by Hall, but they all failed. The boy graduated in 1885 and refused to admit defeat. With home-made contrivances and batteries borrowed from the Oberlin chemistry department the lad struggled on in the historic woodshed against the back of his father's house in Oberlin. He was constantly going to Jewett with his troubles for advice and receiving invaluable help. At last on February 23, 1886, this boy of twenty-two years succeeded where many of the world's eminent scientists had failed.

Yet his discovery was no accident, but rather the climax of logical planning. He searched for a non-aqueous solvent for aluminum oxide and found it in melted cryolite from Greenland. Jewett was mineralogist as well as chemist, and it may well be that cryolite was his vital suggestion. The next step was to find by "trial and error" if this solution of aluminum oxide in fused cryolite would conduct electricity. It did—but no metal resulted. Then Hall discarded his clay crucibles and tried a carbon crucible. Success resulted at once.

Hurrying over to the chemical laboratory with the scarcely cooled little buttons of the precious metal in his palm, he held out his hand to Professor Jewett and said, with ill-concealed eagerness: "Professor, I've got it!"

After three unsuccessful attempts to secure the cooperation of industry and a delay of over two years Hall at last found a haven in Pittsburgh with Captain Alfred Hunt and a small group of metallurgists, who put up $20,000 as capital for the new Pittsburgh Reduction Company. Beginning in late 1888 with a modest daily production of 50 pounds, the business grew to substantial proportions in three or four years.

This success attracted infringers of the Hall patent, and in 1892 suit was brought against the Cowles Electric Smelting and Aluminum Company, of Lockport, New York. It was true that, for a few years, the Cowles Company had reduced aluminum oxide with carbon in an electric furnace, but this was a thermal, not an electrochemical, reaction, and a copper alloy resulted.

Deville's electrolysis of cryolite mixed with salt was cited as antedating Hall's discovery, but the difference was that the great Frenchman did not dissolve aluminum oxide in melted cryolite—and that Deville discarded the process as a failure. Judge William Howard Taft in a Circuit Court of Ohio decided in favor of Hall, January 20, 1893.

As it happened, Hall was employed for a year (July, 1887–July, 1888) by the Cowles Company and gave them an option on his patents, which they dropped with great lack of interest. His discovery was made nearly a year and a half before his contact with this group.

A few years later the Cowles Company

acquired the Bradley patent, which claimed control of a process of passing a current through an ore of aluminum so that it was melted and decomposed. The Cowles Company in 1900 brought suit against the Pittsburgh Reduction Company, lost, appealed and won a seeming victory in 1903, yet with the final result practically a draw.

Patent struggles beset Hall, for in France young Heroult was granted a French patent for the same independent discovery just two months after Hall's discovery in Oberlin and applied for a United States patent.

Hall filed his fundamental patent No. 400,766, on July 9, 1886, but, thanks to Professor Jewett and others, he was able to prove the February 23 date of discovery and was granted his patents on April 2, 1889.

Upon the occasion of awarding to Hall the Perkin Medal in 1911 Dr. Charles F. Chandler, of Columbia, said, "Dr. Hall's achievement certainly entitles him to a place in the front rank of electrochemists."

Dr. J. W. Richards, of Lehigh, added, "I regard the bringing of aluminum into the ranks of the cheaper metals as one of the great metallurgical achievements of the nineteenth century."

Yet when the first American aluminum was made it was locked up in the safe with the sad reflection that nobody wanted it. To secure markets "Hall and his associates had to learn how to cast and to roll aluminum, to forge, draw and stamp it, because no one else cared to learn how, and yet until those methods were learned and perfected, aluminum could not readily be utilized."

Credit must be given this group, now the Aluminum Company of America, for their enterprise, technical skill and success in discovering new uses for the metal and its alloys.

The greatest modern development is really in the field of light alloys, which make possible metal airplanes, light trains, aluminum hopper cars, trucks, truck-tanks, auto pistons, weight-saving passenger busses and its extensive architectural use.

The commercial metal finds its use in the 425,000 miles of aluminum power cable, a million or more cooking utensils, paints and foil that insulate from heat and cold for houses, oil tanks, milk trucks and the heads of British soldiers in the African deserts. Admiral Byrd found the foil convenient in keeping in the heat (reflecting it back) of his Antarctic hut. Now a football player trades a badly cracked rib for a new one of aluminum. Strange uses are legion.

Cleverness in depositing a hard film of oxide on the metal by electrolytic oxidation has opened up new fields. To mention one only, dry point etchings are now made on such hardened plates.

Charles Martin Hall was a genius, a dreamer, a lover of music and art, a philanthropist—and a good business man. When he died in 1914 he willed one third of his estate to his alma mater, Oberlin College, a gift that can now be estimated as worth approximately $15,-000,000.

It is appropriate that Oberlin should have celebrated the Half Century of Commercial Aluminum on February 23. Appropriate, too, that the principal speaker should have been Professor Colin G. Fink, of Columbia, who gave the world chromium plating and now gives it effective and useful aluminum plating of steel and other metals.

THE AGE OF THE EARTH FROM SEDIMENTATION

By Professor GEORGE D. LOUDERBACK
UNIVERSITY OF CALIFORNIA

AFTER the recognition that the sedimentary rocks of the crust are really ancient marine or continental sediments, and that the contained fossils are actually the remains of formerly living organisms, the gradual development of a geological history of the earth became possible. Those who studied these ancient deposits became more and more impressed with the amount of time involved in the vast accumulation of sediments and the great changes in life forms compared with the slight accumulations and changes that have been recorded in human historic time.

Systematic study of geologic history has been in progress only for the last two or three centuries, and during the greater part of that period the students of this science worked under inhibitions and limitations imposed from without, which seriously delayed satisfactory interpretations and definitely modified the conclusions as to the time involved.

The first major limitation arose from the teachings of the church. It was particularly potent because it was a part of each worker's fundamental concepts or philosophical background, instilled into his mind in his childhood and intertwined with his religious views. It prescribed a time limitation for the total history of the earth, the time since the earth's creation, and any proposal to extend this beyond the allotted time was resisted by public opinion (including the opinion of the educated and influential), and the proponent was subject to a charge of heresy.

Viewed purely as a physical geological matter, the question was a problem as to the amount of time required for a given series of events to transpire. It was not solved at the time by setting a definite figure, or even a rough quantitative estimate within wide limits. The limitation imposed by current theological arguments, of approximately 6,000 years since the creation of the earth, was so ridiculously inadequate, that once a realization came of the actuality and nature of the remarkable series of developments and changes which have taken place in prehistoric, in prehuman time (and Adam, the first human of the then orthodox account, you remember, was said to have been created only a few days after the creation of the earth itself), no actual numerical estimate was necessary. Nor was it possible in those days.

As the minds of students of "earth" history were gradually freed from this limitation of orthodox cosmogony, there followed a period during which the more open-minded worked under the impression that there was practically limitless time at their disposal. This period may be considered as beginning with Hutton in the latter part of the eighteenth century and flourishing in the first half of the nineteenth century. Most geologists during that period were busy with reconstructing the succession of events of the past without attempting any estimate of the time involved. A noteworthy exception to this was Lyell, who made an estimate of the time necessary to bring about the change of species during Tertiary time (20 million years) and then, dividing the history since Cambrian time paleontologically into twelve equal parts,

arrived at a total of 240,000,000 years. The basis for his figures was arbitrary and hypothetical.

But soon a new limitation was imposed on geologists. In 1862, Lord Kelvin (then Sir William Thompson) insisted that the practically unlimited time for earth history accepted or demanded by most geologists was opposed to known physical facts. His calculations were based on the internal heat and rate of cooling of the earth, on tidal retardation and on the origin and age of the sun's heat. The first of these methods he considered to rest on the most trustworthy quantitative data. He at first placed the extreme limits for the external consolidation of the globe between 20,000,000 and 400,000,000 years ago, but, in the course of later considerations, he favored more and more the lower limit, his final statements toward the end of the century insisting that it was "more than 20, and less than 40 million years, and probably much nearer 20 than 40" (1897).

This was a great blow to the comparatively recently acquired freedom under which geological thought had been developing, and it came from an unexpected source, and one hard to combat. With much misgiving, geologists were attempting to adjust their concepts of geologic time to this physical limitation when they were placed under still further restriction by another physicist, Professor Tait, who held that the time that could be allowed geologists was somewhat less than 10,000,000 years. This was met by the almost unanimous objection on the part of geologists as being palpably insufficient on the basis of the roughest kind of geological yardstick. While they were not in a position to break down the physical argument, they felt certain it could not be valid. The whole situation created a demand for a quantitative basis for geological and paleontological development, a need not felt in the preceding century.

Ideas of the amount of time involved in geological history have been acquired by geologists chiefly through the study of sedimentary rocks and their contained fossils. Calculations of time based on the thickness of sedimentary accumulations in the main go back not to direct measurements of the rates at which specific sediments are deposited, but to measurements of rates of transportation of material going to make up sedimentary deposits of the present time, and of the areas from which they are being removed. This gives the rate of denudation, and deposition is the complement of denudation. It is sometimes referred to as the hour-glass method of determining geological time.

The usual practice has been to use either mechanical sediments alone, or the total sediments; but some calculations have been based on the removal of calcium and corresponding deposition of limestone, others on the removal of sodium chloride and the accumulation of salt in the ocean.

It is interesting to note that the first suggestion connecting time and deposition was apparently made by the Greek historian Herodotus, who estimated, in the fifth century B. C., that if the Nile were diverted into the Arabian Gulf, it would fill it up with sediment in 20,000 years. In recent time, Phillips seems to have been the first to use the method for estimating the age of the earth, his resulting figure being 96,000,000 years (1860).

Within the last 75 years a number of geologists have made time calculations on the basis of rates of denudation and corresponding sedimentation. While such calculations are based on a simple principle, as in the case of the hour glass, the solution of the problem is fraught with difficulties, uncertainties and arbitrary assumptions. Naturally, therefore, different geologists came to different results, and it would be of no value in this discussion to take them up individually.

But before discussing the method further, I would like to emphasize certain general aspects and results.

The most important result, in my opinion, was that geologists, with but a few exceptions, became agreed that they could not be bound by such low time estimates of physicists as those of Tait or the later figures of Lord Kelvin. This freed geological research during a fruitful period from a restraint similar, if less restrictive, to the older blight from which it had suffered during the preceding century. On the other hand, I feel certain, after studying the various results, that during the first half century after Lord Kelvin's first pronouncement, most of the geologists who made calculations of the time involved in geological history were consciously or unconsciously influenced by the arguments of the physicists to resolve all uncertain points in favor of those giving results requiring lesser time, and to neglect the serious investigation of the effects of certain conditions that, if effective, would probably add to the time total.

The whole situation changed when the implications of the radioactivity of certain minerals was realized. First, the time-restricting structure built upon considerations of a simply cooling earth crumbled. Then geologists were soon told that they had 2 or 3 thousand million years for their earth history. More than that, this large figure was not permissive, it was mandatory. Geologists must take it whether they think they need it or not.

Since this significant change in physical thought has taken place, substituting for an impressed compressive force on the minds of geologists a marked expansive influence of almost explosive violence, a few papers have been published on estimating the age of the earth on the basis of sediments. The writers have accepted at least as probable approximations the results based on radioactive minerals and have therefore attempted to expand the sedimentation figures to fit the radioactive frame.

Barrell in 1917, in an attempt to clarify the cause of the differences between the earlier sedimentation figures and the newer mineral ones, gave a carefully thought-out statement of controlling conditions in sedimentation and factors in the sedimentary record that would add materially to the time required and that were not taken into consideration by the earlier computers. In a recent volume (1931) on the age of the earth published by the National Research Council, Schuchert, under the title, "Age of the Earth on the Basis of Sediments," does not appear in reality to use an independent sedimentation method to determine the age, but by various devices expands the figures from sediments to fit the results from radioactivity and from this determines the average rates of deposition for the different geological periods.

It is a simple conception that if you measure the thickness of a mass of sediments and know the average rate at which it was deposited, you can calculate the time taken for its deposition. Geologists have been able to measure the thickness of many series of sediments with a greater or less degree of accuracy, but the determination of the rate of deposition is a difficult matter. The first figures that appeared to be of more than narrowly local applicability were based on the extensive engineering studies of the Mississippi River. They gave the average value for sediment derived from the denudation of a large area (1,147,000 square miles) including high mountain, intermediate and lowland country under a variety of local climatic conditions. It was believed, therefore, to be a representative figure, expressed in terms of denudation of 1 foot in 4,500 years.

While this figure for the Mississippi drainage area has been favored as a gen-

erally usable rate by many for the reasons just given, it should be noted that other river systems give different rates. The Danube, for example, gives a slower rate, while the Rhone, the Upper Ganges and the Po give faster rates. The rate of the Danube is about 14 per cent. slower than the Mississippi, and the Po about 8 times as fast. The drainage areas of these other streams are all considerably smaller than the Mississippi, that of the Po being only about 30,000 square miles. Some geologists have used an average rate for the different rivers.

To get from the above figures the average rate of deposition, one must estimate the area within which the deposition takes place. For example, the land yielding sediment to the Gulf of Mexico has been estimated at 1,800,000 square miles, while the area of the gulf is only about one tenth of that. The average sedimentation rate in the gulf may then be taken as approximately 10 times the denudation rate or about one foot in 450 years. To get an average value for a whole continent, or for the world as a whole, as some have attempted, requires a series of supplementary considerations and modifications which become more and more uncertain, but which I will not take the time to discuss.

While the earlier calculators of geologic time on the sedimentation basis used a variety of rates, many of which were rather uncritically and arbitrarily chosen, they all agreed in one practice; that is, of basing their particular rates on present-day conditions and action, and applying them uniformly throughout the geologic record. That is, a thousand feet of shale deposited in the Cambrian period was taken to indicate the same number of years as a thousand feet of mud deposited at the present time. This extreme uniformitarian attitude was persisted in even after the development of another branch of geology had distinctly shown that the rate of denudation must vary markedly at different times.

If, for example, we take the average height of North America as 2,132 feet and, for simplicity's sake, apply the rate of denudation of the Mississippi drainage area to it as a constant rate, the whole continent would be reduced to sea-level in about 9,500,000 years. But it is quite evident that as the general elevation is lowered the rate of denudation must decrease and, long before the whole continent is reduced to sea-level, would become extremely slow. Geologic history shows that in a number of periods the lands tributary to a basin of deposition reached a late stage in the erosion cycle, as it is called, and the rate of deposition must have been but a small fraction of the rate calculated from present observations. Rates of denudation determined from any of the great river systems of the present day owe their rapidity to noteworthy wide-spread conditions of continental uplift, combined with great mountain and high plateau building activities of the geologically recent past. While other periods of continental uplift and mountain building have occurred in the history of the earth, there have been intervening long periods of prevailing low-lying lands and slow sedimentation.

The results of the use of present-day rates as uniform rates throughout geologic history had the effect of greatly reducing the calculated age of the earth below its true value, but had the psychological advantage of bringing it within at least the more liberal limitation imposed by the physicists of the time.

The first attempt to develop quantitative values for different specific rates for particular geologic periods on the basis of physiographic control and the relative sizes of denudational and depositional areas for the period under consideration was made as recently as 1926 by H. P. Woodward (quoted in National Research Council Bulletin number 80, pp. 51–54). He postulated that "the curves of denudation values for the pluvio-fluviatile cycle must take on a form

resembling the profile of equilibrium of a stream." He analyzed the present relief of North America into percentage of high, moderate, medium and low, with an estimated rate of denudation for each. Then for different divisions of geologic history he computed from paleogeographic data the area submerged and the prevailing relief distribution of emergent lands. On this basis he developed appropriate rates and applied them to the strata deposited in the selected divisions, giving himself a leeway expressed by minimum, mean and maximum values. The results for the time from Cambrian to Recent approximate those derived from radioactivity, probably more so than would have been the case if their author had not known of the results of the latter calculations. The data on which they are based can not claim a high degree of accuracy, but the improvement over the older type of calculation is very great and warrants the belief that the results are much nearer the truth.

To indicate the quantitative effects on the result as compared with the older use of the present-day rate as a uniform rate, I will give some of his figures. The rates here given are means of those developed by three different methods of calculation.

Present 1 foot in 860 years.
Tertiary 1 foot in 1,206 years.
Mesozoic 1 foot in 1,384 years.
Neopaleozoic 1 foot in 1,646 years.
Eopaleozoic 1 foot in 2,483 years.

His figures give a mean value of time since the beginning of the Cambrian of 686.5 million years; minimum 550.4, maximum 822.6.

Besides the previously mentioned difficulties, there are others inherent in the sedimentation method.

A basin of deposition is not of uniform depth throughout, and the resulting series of sediments is thickest along some belt and thins out towards the edges. In studying the older formations, the geologist can usually not measure the areal extent and thickness throughout and so determine the total volume of sediments, recalculating to an average thickness. The usual method of handling this problem has been to consider the whole body of sediment as essentially a prism, the maximum thickness being measured and considered approximately twice the mean.

Another troublesome problem is that of discontinuities. Series of sediments rarely show evidence of continuous sedimentation. Many small breaks known as diastems may occur, representing cessation of deposition for a longer or shorter time. Most of these may cause no difficulty, as they are probably essentially allowed for in the average rate. But at intervals evidence is found, not of mere cessation of deposition, but of active erosion and removal of formerly deposited sediments. Such breaks may be disconformities or unconformities. In a large basin of deposition, lasting over long periods of time, earth movements may change the location of the shore line, and the relative position of sea level, giving rise to disconformities or, if distortion of the crust is involved, even to unconformities. Such breaks may affect only the border areas of the general basin, and sedimentation may be continuous in the more central areas. This is one of the reasons why it has been the practice in measuring strata for time determinations to use only the maximum thickness of sedimentary groups. They are more likely to represent the more continuous seat of deposition, and any less thick portions can not be so well estimated with respect to the mean or any other definite rate.

But at certain times in the earth's history great areas of former sediments have been subject to erosion, and the material has been carried to parts unknown, possibly under the present oceanic areas. The resultant gap in the record is difficult to allow for in time,

although the intervening marked changes in life forms impress geologists with the idea that a long time is represented. Occasionally an attempt has been made to bridge an unconformity by estimating the amount of change that has taken place in the organisms on the assumption that such changes progress at a uniform rate. But others believe that the earth changes or "revolutions" that produce, among other things, the major unconformities, have an accelerating effect on organic changes. An independent time clock, such as radioactivity may ultimately produce for us, is the only hope I can see of solving this highly interesting problem of organic evolution. At present we must consider time assignments to certain unconformities and disconformities as rather uncertain guesswork.

Another difficulty of time calculations is due to the fact that measured series of sediments do not have the character of uniform rock detritus, but are commonly differentiated into sandstones, shales and limestones. These different types of sediment normally form at different rates. If the total amount of all these sediments were known for a certain series, or if their relative proportions in a measured section corresponded to the proportions of their constituents in the source terrane, no special attention would have to be given the separate types, as the average denudation rate would cover the whole. But in actual measured sections, certain types frequently are in undue proportion as a result of lateral segregation of material; that is, different types are selectively deposited in different areas of the basin. So different rates have to be adopted for the different types. This introduces factors of dubious validity into the calculations. Undoubtedly the rate ratios are not constants under all conditions, and the use of fixed ratios in all sections of geologic history introduces errors the probable value of which it is not possible to estimate at present.

I have tried to show that with all the shortcomings and imperfections of the earlier use of the sedimentation method of estimating geologic time, it served a most important scientific purpose in the latter part of the nineteenth century. A critical examination of its basis and a first attempt to bring it in line with other developments in geology indicate that it is capable of yielding greatly improved results and of aiding a more reasonable understanding of the events of geological history. I have presented no figures of my own of the age of the earth based on a study of sediments, because I do not believe that at the present time such figures would have more than a qualitative value. From that standpoint the most important fact is that the best revised approximation of the time calculated for the more definitely decipherable part of geologic history—from the Cambrian to the present—gives values of the same order of magnitude as the methods based on radioactivity. In other words, at the present stage of development there is no recognized conflict between the results of the two methods. I hope there never will be. Geology needs an independent time clock that runs at a uniform rate, just as we need it in our daily life, and the physicist needs it in his laboratory.

The geologist has an immense number and a great complexity of conditions, processes and events to interpret throughout long stretches of time. For this purpose the ideal would be to have independent time markers at frequent intervals in earth history, so that the variable rates of deposition could be determined accurately for the different periods. In this way geological research would be greatly aided in the interpretation of conditions—geographical, climatic, biologic—that obtained during such periods. Furthermore, proper time allowance could then be made for discontinuities in the geologic record which now must be handled by guesswork.

It is evident that the sedimentation method suffers primarily from variable rates that are difficult to establish, and from discontinuities which it offers no good means of estimating. It is much more suited, in general, for determining extreme minimum values than actual values.

So far I have made no specific mention of Pre-Cambrian time. Its estimation by sedimentation method encounters all the difficulties outlined above and others of a formidable character. The chief of these is the lack of satisfactory means of correlation. To explain, it may be pointed out that in no continuous section on the earth do we find all periods of earth history represented by maximum values of sediments: usually a number of periods are not represented at all. In dealing with time from the Cambrian to the present we may correlate disconnected sections in different parts of a continent or even of the world by means of fossils. Thus we may find the maximum development and best measurable section of one period in Pennsylvania, and of another period in California, and piece them together from all parts of the continent to calculate the total time involved. But the Pre-Cambrian rocks carry few or no fossils, and we can not well piece the various sections together and be sure we have the whole history arranged in proper sequence. Furthermore, discontinuities are most strikingly developed, and one is at a loss to make an estimate, even roughly, of time involved. The minimum value given by sedimentation under present knowledge is therefore likely to be in much greater measure below the actuality than it is in later geologic history. In this vast stretch of earth history, a satisfactory radioactive time clock would be of especial value, for it would not only give time, but give us also a greatly needed means of correlation of different sections.

Before leaving the sedimentation method entirely, I must mention a comparatively recent development that gives surprisingly accurate time values: the study of varve sediments. By this method time involved in certain sediments can be determined by counting individual years, with results of a high degree of accuracy if good comparative sections can be obtained. Unfortunately, this method can be used only for small fractions of the geologic record. It was first proposed by De Geer (1910) in connection with glacial sediments. The contrast between the frozen winter and the active summer discharge of detritus gives rise to marked seasonal layering in the deposits and allows their recognition even in ancient sediments. A similar method has been applied to certain other sediments believed to show seasonal banding, but it is yet questionable how far this method can be carried. In deltas or other river sediments the laminations may allow the counting of floods, but, depending on conditions, floods may occur oftener than once a year, or, in certain arid streams, once in several years, and the time element becomes more uncertain.

In conclusion, time estimates from sedimentation are only accurate in certain small fractions of the geologic record, give fair approximations for other parts, but are not suited, unaided, to give a satisfactory figure for the total age of the earth. But the relation of sedimentation to time is a very valuable conception that is bound to be of constant importance in geological interpretation. Even now, if we accept all the results of radioactivity, we must use the sedimentation method; for the points on the radioactive time scale are very few, and the lengths of time to be assigned to specific periods must still be determined by the ratios and rates developed from studies of the sediments, and it may be necessary to use them for this purpose indefinitely.

SOIL POPULATIONS

By Dr. ARTHUR PAUL JACOT

APPALACHIAN FOREST EXPERIMENT STATION, ASHEVILLE, N. C.

Ants and rodents are usually thought of as constituting the population of the soil, as well as earthworms and some insects. The élite of pedology also recognize the hosts of bacteria and protozoa found throughout organic soils. One may be vaguely conscious that some insects get into the soil for reasons of their own. But this assortment of odds and ends of the animal kingdom are local in their effects as compared to that of the minute segmented-animals (arthropods) so numerous and generally distributed in organic soils as to be of outstanding importance in making and keeping the soil full of minute channels which make it possible for rainwater to enter it instead of running off the surface. The intricate, ramifying patterns which these microarthropods establish are of far greater importance in water percolation than mechanical soil porosity—as evidenced in soil which has been so eroded as to have lost this *animate layer*. Not only do these animals extensively channel the soil, but they greatly increase its fertility when not interfered with by man. To follow the course of events let us begin with a moribund tree.

As the tree dies, molds and mildews develop in its inert parts, gradually softening them up. This is just as true of the extensive underground system of roots as it is of the familiar ramifying crown. As the roots are softened by the fungi the host of minute segmented animals find their way in through cracks in the root bark and through the ends of rootlets which died some years earlier. In fact, the root system of a tree, like its crown, is in a continual state of change, old rootlets dying and new ones being formed. This occurs through all the years, once a tree has attained a fair size and degree of growth. Such changes in the root system are due, among other factors, to very local and slight changes in water content of the soil. No sooner are the unused rootlets softened by fungal decay than the minute arthropods which live in the soil and have passageways along the roots and rootlets eat up the decayed wood and thus hollow out the rootlets. These excavations are carried on by generation after generation of the saprophytic arthropods, extensive family-trees being developed within the root of a single large tree. As the root-bark is much more resistant to decomposition it remains as a cylindrical wall about the tunnel, with holes here and there where root branches originated. As may be judged, the process of the eating out of the roots is carried on from different directions, so that, at times, the tunnels thus formed meet. Long after the entire tree is dead the work goes on until the hold of the tree on the soil is so weakened that it comes crashing to the ground, leaving a large depression where the butt once stood. The rain water accumulating in the depression drains through the partly excavated roots and is distributed through the surrounding soil, thus changing the water relations and water supply of the neighboring plants.

As most of the saprophytic (dead wood eating) microarthropods are less than a millimeter (a twenty-fifth of an inch) in breadth any one of them would be lost in a root two or three inches in diameter. Yet some of them are so much smaller (one-tenth millimeter broad) that they can eat out the small rootlets, while the immature stages (of which there are four in the saprophytic mites) are very much smaller than the adults.

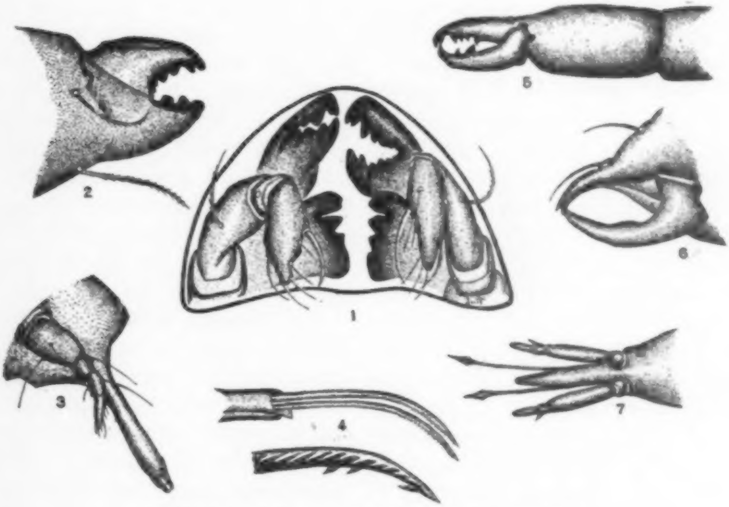
It is in fact the immature animals which do the bulk of the eating. Although soft and white, while their parents are hard and amber-colored to brown, they have very hard, efficient mouth-parts. For instance, the mites have a pair of mandibles which much resemble tinner's snips, a pair of maxillae which resemble heavily nicked chisels, and a pair of finger-like palps, besides a tongue-like ligula. These organs are so mounted in the front of the head that the mite can put the full weight and strength of its eight-legged body behind them. The adults, though provided with the same kind of mouth-parts, spend a good part of their time wandering about in search of mates and of thrusting their eggs in nooks and interstices where the young larva will find shelter and an abundance of food. The food is digested by bacteria and/or protozoa which live in the alimentary tract.

Gradually, as the colony develops, the wood becomes more and more riddled by the minute tunnels and galleries until the entire root becomes sponge-like, except that the channels usually run with the grain. Some of the excavators, on the other hand, are quite devious in their eating. A factor which causes turns or changes in orientation in some species is the molt. As the six-legged larva grows larger and fatter the body wall becomes too tight. The animal becomes lethargic, stops feeding and a new coat forms inside the old, which cracks open, and the animal steps out with an additional pair of legs. It then proceeds to feed where it had left off, though not always in the same direction. This process is repeated four times to reach the state of maturity so that as one traces out the tunnel of any one individual, one may find four cast-off "suits of clothes" as well as a line of feces. It is the row of feces left along the floor of the tunnel that contributes to the fertilizing action of these animals. For, though small, they make up in numbers what they lack in size.

The process of excavation is not carried out by the saprophytic mites only. Several other groups of minute arthropods are engaged in this process. Moreover, the root may not be entirely cleaned out. A central core of very much channeled wood, with very thin partitions still standing between some of the tunnels, may remain in the root.

As such a root system becomes open to water action, sedimentation begins. The feces are washed to the outer reaches of the system—the tips of the rootlets. Mineral and organic particles are introduced from the outside, especially from the hollow caused by the fall of the tree. Moles and other animals may break through a hollow root. External pressures, due to the growing of nearby tree roots, freezing water, burrowing animals and thrusting moles, may cause some of the hollow roots to collapse. Rootlets of other trees or of bushes, extending in the direction of more water, will find their way into the hollow root and develop freely within it, finding free rain-water and concentrated organic matter. Little by little the entire root system of the old forgotten tree becomes filled up. Where once there was a live root, there has succeeded the extensive system of a fungus, then myriads of minute arthropods with their accompanying predators and parasites, a vast underworld of many species, then running water bearing its burden of organic debris, and finally a tortuous black streak through the mineral soil. Such streaks may be observed along road cuts passing through old woodlands, and their contents removed, and examined under the dissecting microscope.

In the meanwhile other trees, bushes and herbaceous plants have grown senile and their roots have been eaten out. Annual plants yearly contribute their quota of dead roots and rootlets to the



MOUTH PARTS OF SOME SOIL MITES

(1) ENSEMBLE OF A TYPICAL "SAPROPHYTIC" MITE (ORIBATIDAE), AS SEEN FROM IN FRONT (FORESHORTENED MANDIBLES ABOVE, MAXILLAE BELOW, WITH PALPS AT SIDES). (2) A SINGLE CRUSHING MANDIBLE, FROM SIDE, TYPICAL OF MOST "SAPROPHYTIC" MITES. (3) ATTENUATED MANDIBLE AND PALP OF PELOPS (A SUCTORIAL ORIBATID), FROM SIDE. (4) VERY MUCH ATTENUATED MANDIBLES OF GUSTAVIA (A SUCTORIAL ORIBATID). (5) MANDIBLE OF A PREDACEOUS MITE (PARASITIDAE). COMPARE THE POINTED CUSPS WITH THE MOLARIFORM CUSPS OF THE SAPROPHYTIC TYPE (1). (6) MANDIBLES OF A PREDACEOUS MITE (RHAGIDIA). (7) STYLET-SHAPED PIERCING MANDIBLES AND PALPS OF A PREDACEOUS, SUCTORIAL MITE (SMARIS).

wood-decaying fungi and the host of saprophytic animals that live in the litter and in the soil. The process is continuous. The animals eat night and day (where there is no day) and are stopped only by the processes of molting and of freezing. As soon as thawed they continue their feeding. Such animals may be frozen repeatedly through the winter, feeding between the freezes. To them freezing is sleeping.

Soil populated by annual plants, as is characteristic of mull soils, and especially grassland, is so densely interspersed with minute rootlets, at least some of which die each year, that the soil is kept in a constant state of microchanneling, and these channels are rapily filled with organic debris, if nothing else the feces of the excavators. It is for this reason that grassland soil is black and friable, while woodland soil with no herbaceous cover becomes hard and yellow.

In addition to the root excavators, the soil is populated by a group of minute arthropods which burrow about in the soil, filling it with minute channels which have no particular relation to rootlets. The channels wind about in an intricate, seemingly aimless way. Compared to the granular structure of the soil, the channel walls are smooth, resembling those of earthworm burrows, but in this respect only, for worm burrows are much larger and quite direct and vertical. Occasionally they widen out to form galleries or chambers, especially under a pebble or bit of stone, which is usually quite wet on its under face compared to the surrounding soil. Plant roots and mineral grains occasionally enter into the structure of the walls.

It is quite conceivable that this general soil channeling is due to several factors. Roots alone are not responsible, since plowed land abandoned for a

few years, and supporting a very meager weed flora, is so channeled. One of the factors is the ability of some of the mites to dig. Those of the genus Lohmannia are built like a mole and have the anterior legs fitted for digging. Epilohmannia, though less stocky and longer legged, is also a common inhabitant of soil. Other genera, the species of which are found above ground, as well as within, have the tarsi of the first pair of legs armed with a stout, curved spine. Species of Xylobates have two or three stout spines on their anterior tarsi and the body is quite stout and unconstricted. Other soil mites, which probably do no digging but aid in maintaining these passages, are not particularly modified for an under-ground existence. In fact, many of the litter-inhabiting species descend into the soil when the litter gets too dry or to lay their eggs or for other reasons, so that there is a continual migration between the surface litter of organic plant remains and the soil itself.

This is true not only of the mites but of many if not all of the other groups of soil (and litter) animals. Springtails (Collembola), the group of microarthropods ranking next to the saprophytic mites in numbers in the soil and litter, are very active, and continually on the move. Most of the soil species belong to primitive genera and are colorless (white) and eyeless or with reduced eyes. Some of the species are saprophytic and some are carrion eaters. Although not diggers they help in maintaining the soil channels. Yellow-tips (Proturans), the most primitive of insects, having no antennae but rudimentary abdominal legs, are present in most soils in varying numbers. They are probably eaters of decayed plant tissues. Their narrow heads, elongate anterior legs and tapering yellow abdomen, held slightly elevated and continually vibrating, are their distinctive features. Minute millipedes of the order Pauropoda are soil dwellers. The minute centipede *Scutigerella immaculata,* seven millimeters long and milk white, is fairly common. Very much resembling it is Japyx, another primitive insect easily distinguished from Scutigerella by its brown, caudal, nipper-like appendages.

Some of the larger millipedes are also dwellers of the soil under certain favorable conditions. They require considerable moisture. During times of drought the litter species enter the soil to estivate. In fact, woodland soil becomes highly tenanted during the autumn with species of insects which spend their summers in neighboring fields or the upper strata of the forest. The soil offers them shelter and a certain degree of warmth through the winter. Blake found that in the warm temperate zone these winter migrants moved between the soil and the litter during each warm and cold spell. This would keep the woodland soil much more open and channeled through the winter than through the summer.

Of the predaceous groups there are many kinds of mites, some centipedes, Japyx and certain beetles. Ants are much more common than is generally known. As the commonest species are minute and soil-colored they easily escape notice. They and the earthworms have their own shafts and galleries, thus adding considerably to the opening up of the soil, but contributing still more by bringing the mineral soil to the surface and spreading it out over the organic layer of the surface. In this way they are important as mixers, and being ubiquitous, even to the extent of one or two colonies per square yard, they are of considerable importance. The numbers of earthworms have been much underestimated, because the popular conception of earthworms is the large angle worm. There are, however, several small species and some minute forms which

contribute their mite to soil structure, making up in numbers what they lack in size.

Reliable population studies can only be carried on with special collecting methods adapted to the particular group being investigated. The best sampling method for ants is useless for earthworms. Most of the methods that have been used for soil population studies are designed particularly for securing the larger insects and are therefore highly erroneous for the microarthropods, minute ants and earthworms. Using more appropriate methods, I have found one thousand to two thousand microarthropods per square foot of woodland and grassland soil, and a few hundred per square foot of plowed fields abandoned three or four years and grown to tall weeds.

The above considerations have not taken into account that enormous group of inconspicuous and minute threadworms (Nematodes) which clothe the earth and inhabit all the larger organisms. Here again special collecting methods are needed. Many of the species are saprophytic and aid considerably in the reduction of organic matter. Bear-animalcules (Tardigrades), though found in such limited numbers as a dozen or more per square foot, contribute their share in maintaining soil tilth and soil fertility.

It is not the very local effect of such conspicuous animals as the woodchuck or prairie-dog which contributes markedly to soil fertility, soil mixing (plowing) and soil channeling, but the effect of the myriad animals found throughout all organic soil, animals which are not of such microscopically small size as to pass between soil particles, but large enough to establish and maintain innumerable channels many times larger than the interstices of the soil particles and soil granules, that are of cardinal importance to soil management. When these minute animals are removed by intensive erosion they must become reestablished before soil can again become fertile and generously receptive to rainwater.

SCIENCE SERVICE RADIO TALKS

PRESENTED OVER THE COLUMBIA BROADCASTING SYSTEM

SOUNDING THE SEVEN SEAS

By Commander J. H. HAWLEY

ASSISTANT DIRECTOR, U. S. COAST AND GEODETIC SURVEY

SEVERAL months ago a small ship was cruising along the Pacific coast of the United States. In the pilot house the officers on watch were paying close attention to a small mysterious-looking black box which seemed to be putting on a miniature display of fireworks.

This craft was a ship of the United States Coast and Geodetic Survey; one of a fleet which is constantly engaged in surveying our coastal waters in order to provide the marine charts required for ship navigation. The black box was the main unit of an echo-sounding instrument—a remarkable device which measures the time required for a sound to reach the bottom of the ocean and return as an echo, computes the distance traveled and then indicates the depth under the ship by flashes of red light on a graduated dial.

Work that day was rather monotonous, for the ocean floor, some 50 miles out from the coast, was flat as a pancake. Suddenly something seemed to go wrong; flashes of red light came from all positions on the dial and it looked as if the instrument was completely out of kilter. This was not the case, however, for subsequent investigation showed that the ship was passing over a massive submarine mountain, previously unknown, which rises over 7,500 feet above the ocean floor.

And thus one more of the ocean's secrets was revealed—secrets which have been disclosed slowly by hazardous exploration and painstaking investigation. This search for knowledge has been carried on almost from the time when primitive man first gazed out across an apparently unlimited expanse of water and, no doubt, speculated on what lay beyond the horizon and what existed beneath the surface of the sea.

As man became more daring and ventured farther and farther from land, information with respect to the extent and location of the oceans was gradually accumulated. Much later, in comparatively modern times in fact, comprehensive knowledge of depths and the configuration of the sea bottom in coastal areas became more and more essential for ship navigation. Finally there was need for information concerning oceanic depths beyond the requirements of navigation, for various branches of scientific research and for such practical purposes as the laying of submarine telegraph cables, location of fishing banks and the like.

At the present time our geographic knowledge of the extent and boundaries of the oceans is practically complete, and most nations have executed surveys as far out from their coasts as is necessary for navigational purposes. Beyond this limit our information concerning the depths and other features of the sea is much less comprehensive. We do know enough, however, to give us some idea of the general conformation of the ocean bottom and of certain characteristics, such as temperature, salinity and marine life, of the waters which cover about 71 per cent. of the surface of the earth.

As might have been expected, one of

the first facts disclosed by early investigations is that the configuration of the ocean bottom does not differ greatly from that of adjoining land areas. And so we find submerged mountains and plateaus rising to form shoals or banks; submarine valleys known as troughs or trenches; ravines in the continental shelf called furrows, and other forms with which we are familiar on land.

At some places the bottom sinks considerably below the general level and forms marked depressions which are designated as "deeps." This term is generally used for areas where the depths exceed 18,000 feet and on this basis there are some 50 known deeps throughout the oceans of the world. Probably the most interesting of these features are the deeps, each of which constitutes the greatest known depth for the particular ocean in which it is located.

The principal deep in the North Atlantic Ocean is the Nares Deep, a short distance north of Puerto Rico, which was discovered in 1902 and has a depth of 27,972 feet, or about five and one third miles. In the South Atlantic Ocean a maximum depth of 26,575 feet was recorded in 1926. The greatest depth found in the Indian Ocean is the Wharton Deep, close to the south coast of Java, where you would have to go down 22,968 feet to reach the bottom. In the Arctic and Antarctic Oceans maximum depths of 17,850 feet and 14,274 feet, respectively, have been measured.

I have left the Pacific Ocean until the last, for in this ocean, close to the Philippine Archipelago, we have the greatest known depth of any of the oceans of the world. In this region a remarkable trench or submarine valley extends over 500 miles along and past the east coast of the island of Mindanao, and in this trench is located the Mindanao Deep, where, as discovered in 1927, the depth is 35,400 feet—over six and one half miles; a depth so great that if Mount Everest in the Himalayas, the highest known mountain in the world, were placed in the Mindanao Deep, its summit would be over a mile below the surface.

The Mindanao Deep is one of several extensive depressions in the western Pacific. Next in rank is the Tuscarora Deep near Japan with a depth over 32,000 feet. The Nero Deep, near the island of Guam, and the Aldrich Deep, a short distance northeast of New Zealand, both have depths of about 31,000 feet.

That the great depths of the oceans are of considerable general interest is indicated by the frequent inquiries which are received concerning them. One popular idea, much in evidence when a marine disaster occurs, is that an object sinking in the ocean eventually will reach water so dense, under the enormous pressures which exist, that it can not be penetrated; the result being that the object, after reaching a certain depth, will there float indefinitely. This thought also has attracted the imagination of writers of prose and poetry on many occasions. For instance, we have these lines by Longfellow:

> Beyond the fall of dews
> Deeper than plummet lies,
> Float ships, with all their crews,
> No more to sink or rise.

It is rather distressing to cast discredit on an idea that can be expressed so beautifully. As a matter of fact, however, water is almost incompressible and any object heavier than the water it displaces will sink and will continue on to the bottom, regardless of the depth.

Apparatus for measuring depths has been gradually developed through the ages, but it is only in comparatively recent times that the greatest depths of the oceans could be plumbed. The mod-

ern equipment for direct measurements is an electric or steam sounding machine having a reel on which several miles of fine piano wire are wound. To the end of this wire is attached a pear-shaped sinker of cast iron weighing from 35 to 75 pounds.

The wire in its downward fall passes over a sheave of known circumference which registers the length of wire run out in about the same fashion as the speedometer of your automobile. When the bottom is reached, the cast-iron sinker is automatically detached and abandoned, so that the wire can be reeled in with less danger of breaking.

Nothing is more impressive of the great depths of the ocean than to watch, second after second, minute after minute, for a half hour or more, the rapidly revolving drum of a sounding machine from which the wire unwinds. Finally the bottom is reached and there comes to the observer a sudden realization of his elevation of several miles above the bottom of the sea. It would require over two hours to sound the Mindanao Deep with a sounding machine—about one hour for the weight to fall and an equal time to reel in the wire. Advantage is taken of wire soundings to obtain specimens of bottom material and to secure water samples and measure temperatures at any depths desired, various instruments being available for these purposes.

Temperatures of sea water from the surface down to the bottom have been obtained at many points in the various oceans. As would be expected there is great variation in the surface water temperatures in different latitudes, and these temperatures decrease more or less rapidly with increase in depth. Regardless of the latitude, however, at a depth of about one mile, the temperature drops to a little above the freezing point of fresh water and then remains practically constant all the way to the bottom, whatever the depth may be.

Valuable as they were, the gradual improvements in sounding machines and accessories have been overshadowed in recent years by the development of echo-sounding instruments which I have mentioned. Sound travels through the water at a speed of about 4,800 feet per second so that a sounding which formerly required an hour or more can now be obtained in a few seconds, and this without stopping the ship which, of course, was necessary with the older methods.

In depths up to about 600 feet a ship, running at full speed, can now obtain four soundings every second; while in depths from 9 to 120 feet a new instrument, recently developed by the Coast and Geodetic Survey, measures depths at the almost incredible rate of 20 soundings per second.

Much work has been done in oceanic research, but the field is so vast that we have made scarcely more than a beginning. With the development of echo-sounding instruments and their increasing use, not only on survey ships but also for navigational purposes on vessels of the Navy, Coast Guard and merchant marine, it is apparent that a new era is dawning in this study. I am confident that our knowledge of the seas, at least with respect to the configuration of the ocean bottom, will increase much more rapidly from now on.

In a short talk of this nature it is possible to cover but a few phases of a topic so extensive as oceanography and only to touch on the high spots of the branches selected, although I seem to have devoted my time mostly to the low spots. In so doing I hope that I have been able to tell you something of interest. I am sure we can all agree on one thing at least, which is that the subject certainly is not a dry one.

THE LURE OF ARCHEOLOGY

By N. C. NELSON

CURATOR OF PREHISTORIC ARCHEOLOGY, AMERICAN MUSEUM OF NATURAL HISTORY

ARCHEOLOGY, or the study of relics pertaining to man and to his mode of life in times before history came to be written, has been a topic of considerable interest to this country for about 150 years. It began to attract attention immediately after the Revolutionary War, when many of the discharged soldiers moved out into the Ohio Territory to take up land and there discovered numerous great mounds and other earthworks, which they erroneously attributed, not to the Indians, but to a mysteriously vanished people whom they called the mound-builders. For about a century thereafter, or throughout our busy pioneer period, actual antiquarian pursuits, as far as we know, were limited to a comparatively few individuals, either of a scholarly turn of mind or endowed with the instinct for collecting. Among these early amateurs, it may interest you to know, were at least two Presidents of the United States, one of them being Thomas Jefferson. But during the last fifty years trained investigators have come forward, and one of the results of their intensified and improved work is that to-day widespread popular interest, not only in American antiquities but in the archeological findings of the entire world, has become generally apparent and is steadily growing. It is my purpose on this occasion merely to suggest to you some probable explanations of this phenomenal enthusiasm for knowledge about prehistoric man.

If by chance you are not personally fascinated by the collection and study of Indian relics, or if you are not directly aware of the public response to these activities, allow me to call your attention to a few proofs. First, there is the daily press, which in recent decades has furnished an ever-increasing amount of news about archeological discoveries in all parts of the world. The opening, for instance, of Tutankamen's tomb in Egypt in 1922, and the later removal of its contents, were considered "good copy" off and on for a period of years. And when last spring a mummified body was found in Mammoth Cave, Kentucky, the details were circulated through our newspapers from coast to coast and doubtless reached even the foreign press. Then there is the lively interest shown of late by the Boy Scouts and similar organizations in hunting and digging for arrow-points and such things all over the country. Many individuals, within and without these groups, are making private collections of more or less value and far more stimulating, as I believe, for independent thinking about human affairs than, for example, the collecting of postage stamps can ever be. Incidentally, I may tell you that scarcely a week passes that I do not personally receive a letter from some young man or woman—even occasionally from grammar school children—who wants to know how to become an archeologist. Finally, in our larger cities, like New York and Chicago, the museums are visited annually by hundreds of thousands of school children, and they are giving special attention to the archeological exhibits. In the meantime, several of our universities have acquired small collections for teaching purposes, and the day is probably not far distant when even our secondary schools will have displays of Indian relics of local origin to serve as a supplement to

the teaching of American history. Why, we may well ask, this all-round genuine interest in prehistoric archeology?

A precise and positive answer can not of course be given in fifteen minutes. Indeed, there are doubtless many answers, and by exploring our subject, even if hurriedly, from center to circumference, as it were, we shall certainly discover some of them.

Our most natural starting point is at the circumference or vague outer limits of the field. Here, then, we may properly begin by asking whether the reason for the present popularity of archeology may not be connected with the general truth that we are all, without perhaps clearly knowing why, deeply interested in everything that directly concerns human kind. Most of us, in our idle moments, are talking about ourselves and our acquaintances, *i.e.*, about man, and only rarely about things. The ancient Greeks actually had a motto which read "Know thyself" and which indicates what they considered the most important subject for study. Pope, one of the English poets, suggested the same idea when he wrote that "The proper study of mankind is man." In short, it appears that there is no escape from the conclusion that in man—in ourselves—are centered finally all our instinctive and rational interests. Why otherwise are fiction and biography so popular, unless it is because we never tire of reading about human behavior? Even the comparatively dry facts of ordinary history have a wide appeal, and when it is realized that archeology is after all only a supplement to history, perhaps we have the basic answer to our question.

But for present purposes we require a more immediate and concrete explanation. What precisely is, then, the lure of archeology or how in specific terms account for its broad appeal? To come to the point at once, may not our common, though perhaps often unacknowledged, love of romance be part of the secret? What youth, for example, has not at some time or other wanted to be a pirate or a treasure-seeker, a prospector for gold, a big game hunter, an explorer or even a merely ordinary traveler? Now it so happens that archeology satisfies in a unique way these longings for adventure. The search for archeological treasure, entered upon by digging in a cave or by walking open-eyed across a plowed field, takes one instantly out of the normal daily routine into direct contact with men and things of an earlier, unrecorded time, and thus gives present life a new and broader significance.

Coming to closer quarters with the subject, perhaps I can do no better than to begin by confessing why I myself became interested in archeology, interested sufficiently to make a lifework of it. It happened this way. As a student in high school I suddenly found it necessary to know something about how, when and where man really originated and, in general, how things as they are in the world to-day came to be so. My history books did not tell me. My teachers either could not or would not enlighten me. As a last resort, therefore, I had to turn to prehistoric archeology. You may easily guess that I have not yet found the final answers to all my questions; but I trust you will believe me when I say that I feel sure we are well on the way to solve these perplexing riddles.

When it comes, now, to other people's interest—your interest—in archeology, I suspect there are many different replies. For an opening I venture to guess that some of you are collecting Indian relics simply for the pure joy of collecting. This collecting habit is a trait which we share with some of the birds and mammals and consequently need not apologize

for or even try to explain. It is enough that its legitimate exercise gives us satisfaction. But no intelligent collector is likely to go very far with his hobby of gathering primitive implements without being impelled to think about the various uses to which they were put and perchance also about what relation they bear to our similar modern implements. Sooner or later, therefore, he will be picturing to himself the kind of life the ancient makers lived; and, if he possesses a complete series of chronologically arranged specimens, he will be perceiving also how by slow stages of improvement the simple early inventions of stone, bone, wood and shell gave rise to our present metallic contrivances. This visible demonstration of origin by gradual modification of most of our own material equipment for life is perhaps the greatest lesson in evolution that archeology has to teach.

We must conclude by citing yet another possible reason for current popular interest in our branch of study. Archeology, while by courtesy called a science, is not quite in the same class with such exact or highly technical inquiries, as, for example, physics and chemistry. In other words, archeology is a study which can, within certain limits, be profitably pursued by any one with ordinary common sense. Special training for effective work is to-day provided by several of our universities; but there are still a number of workers in the field who, without such professional equipment, have for years been making important contributions to anthropological science. It may well be, therefore, that archeology or prehistory is popular in part for the simple reason that it is a study of everyday things—a study, namely, of earthworks, cemeteries, village sites, house ruins, household furnishings, tools, weapons, bodily ornaments, etc.—in brief, a study of things that we all know something about and therefore can to some extent understand. If in addition to this the amateur is aware of the scientific requirements of his task, and knows that by partaking in this world-wide investigation he is really adding new facts to our stock of knowledge about the development of human civilization, he is bound to enjoy a measure of satisfaction such as every discoverer knows.

IN QUEST OF GORILLAS

V. ELUSIVE GIANTS OF THE MOUNTAINS

By Dr. WILLIAM KING GREGORY

CURATOR OF COMPARATIVE ANATOMY AND OF ICHTHYOLOGY, AMERICAN MUSEUM OF NATURAL HISTORY; PROFESSOR OF PALEONTOLOGY, COLUMBIA UNIVERSITY

THE mountain forest in which the Kivu gorillas roamed and made their one-night camps presented a riotous confusion of new growths. Most of the primal forest had been removed, but there was still a residue of the Old Guard here and there, an enormous tree whose trunk and main limbs were contorted beneath the tightening coils of heavy lianas and vines, while besieging forces had eaten into its very core; but it still reared its head far above the surrounding bush, and its buttresses had defied the assaults of many storms. Here among these grand trees the shaggy black giant apes found a magnificent setting. They too doubtless appreciated the big trees as affording comfortable and dry beds in the tangled branches or at the foot of the buttressed trunks. But to our eyes even the trees of second growth were strange and beautiful, while the thick underbush included an immense variety of bushes and bright flowers, all of which were probably skilfully classified by the gorillas into edible and worthless classes.

As one went further into the forest, up the long curved mountain ridge that surrounded our camp on the west and north, one discovered on his right a curving valley, hereafter called the "Valley of the Elephants," which was mostly screened from view by the high bush. This was traversed by a meandering trail made by wood-cutters; along this trail one could find many delightful details, a beautifully woven purse-like nest hanging from a branch overhead, a big land snail pursuing his leisurely flowing way along the path, a male hornbill flying along and making the silent forest resound with his brazen cackling and whooping.

The first time I discovered this valley I was amazed at its beauty. Near me were high trees with light willowy curving trunks and joyous sprays of leaves at the top. All around were high straight stalks with broad ovate leaves that caught glints of sunlight. I could look away down the slope to the bottom of the valley and with my glasses search the tangled bush there in hopes of seeing something stir. Tensely I waited for a hairy black arm to shake the bushes or a velvet black muzzle to yawn and emit a sharp bark. But nothing stirred and the silence was broken only by the mocking twitter of small birds. Turning my gaze near by, however, I discovered a meandering elephant trail, as the big beast had crashed through the underbrush, leaving dung that was not old in appearance. The next day near the upper end of this valley I found another elephant trail, which showed what very steep mountain slopes elephants can climb.

A little way to the northeast of our camp was a place in the forest which afterward became famous to us and which I shall here call *"L'Hotel des Gorilles."* This place was in a general way above and behind a hill which I shall call "Vierstraet's Hill," because it was immediately behind that gentleman's residence. This hill provided me with a training ground in woodcraft, since I frequently got myself lost in its high grass and thick bush and then had an exciting time finding myself again.

But after I purchased the mgoosu from a native I easily hacked my way about in this jungle, leaving a broad trail that not even I could lose on the way back. After several preliminary explorations in this region, one day I took one of the natives with me and made a wide detour around Vierstraet's Hill and the *Hotel des Gorilles.* We passed around a shoulder of our mountain that faced northeast toward the lake and obtained a glorious view of the real Lake Kivu to the north, which was far more extensive than the small southern bay that we faced from our camp. Circling away from the lake view, we entered the forest and came into the "Valley of the Elephants" on the opposite side from that which I had first entered. To our great surprise we found ourselves in a labyrinth of recent elephant paths that were broad lanes through the thick jungle. These paths ran in many directions and were only a few days old. I wondered how the gorillas liked to have a herd of elephants crashing through the forest, but as both gorillas and elephants had vacated the premises my black boy and I retraced our devious way back to camp.

Many a day I wandered in the forest in the neighborhood of our camp, with a mounting desire to spy on the elusive gorillas. The curving "Valley of the Elephants" sloped upward in the direction of the main path up the mountain and finally crossed it, traversing a very deep notch, down which one went far more readily than one ascended the opposite side. Afterward the path wound along, getting higher and higher until one could obtain a fleeting view of the mountains south of Bukavu. Then began the longest and steepest descent of all, compensated by a glorious view of the high and jagged Mt. Kahusi toward the west. The path led through a deep and dark valley, up a steep escarpment on to a plateau of bamboos interspersed with giant trees, where gorilla beds and dung were seen, then down into a big and very wet marsh, through which we four once picked our way in vain pursuit of gorillas ahead. The gorillas finally crossed the marsh and in the late afternoon re-

Photograph by H. C. Raven

MOUNT KAHUSI.

Sketch from author's note-book

THE REAL LAKE KIVU.

tired into the shades of the forest, while we gave up the chase for the day. But sooner or later each one of us saw living gorillas in their native forest.

A day or two after setting up our permanent camp at Tschibinda, Raven and McGregor were on the main path leading up toward the ridge when they came near a party of gorillas. They heard several barks, saw the bushes wave and one great black arm appear for a moment, then a black head with a rufous crown; but at this time they were intending only to study the habits of gorillas and there was no opportunity to place the definitive shot through the head to which Raven was restricted by the circumstances mentioned below. The light for photography was very poor, the gorillas were nearly always heavily screened and in our experiences no one was successful in getting either cinema or still photographs. There was room for difference of interpretation as to how many gorillas barked on this occasion, but there seemed to be several. The natives that morning had reported a band of fourteen in the neighborhood, but there was no means of testing their statement. In fact, there seemed to be considerable variability in the number of gorillas in one band, but there was some evidence that some bands included a very large male, at least one other male, several females and young.

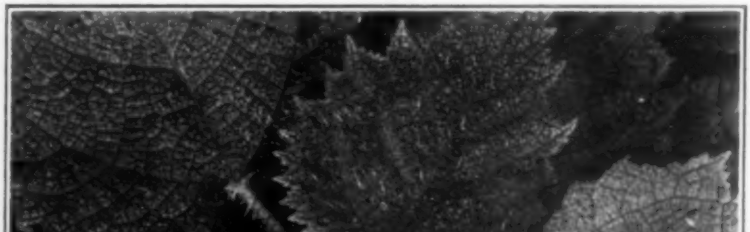
My first visual contact with the gorillas was on one occasion when I went with Raven and several Batwas after a band that had been reported by the natives. First we walked up the main path to the top of the first ridge, down the steep valley, then up on the other side. Then we left the path and began to crawl through the underbrush, following the erratic trail of the gorilla to right or left, up and down the steep slopes. Climbing over great logs, slipping and sliding on the steep slopes were not so bad, but stooping down to the ground and crawling through small openings in the bush, wriggling on one's stomach, breaking the

entangling vines or trying to untangle one's self from vines and thorns and striving to avoid the nettles, made progress fairly difficult for a middle-aged beginner.

After a while there came a loud scream and a scattering of the Batwa. At last, I thought, there is the gorilla! But no, it was only a black bush-pig which had been caught in a snare set by the Batwa the day before. There was further uproar as the pig was quickly speared; then a most ingenious trussing up of the heavy animal until his hind feet crossed his throat and his forefeet were tucked against his sides, after which Nyumba, the most powerful man of the hunters, took the pig on the top of his head and walked nonchalantly away with it down the mountainside.

We picked up the gorilla trail again and began a new chapter of "reeling, writhing and wriggling." After a long time there was a loud bark, a sudden waving of bushes and the gorilla disappeared. Raven and several of the Mambutis slithered away like lizards through the bush. When I and my personal attendant Batwa came up with them a council was held. The Batwa told Raven that very few gorillas were left in the neighborhood, that in particular this gorilla was now far on the other side of the steep valley and could not be overtaken as he was thoroughly aroused and could move through the thick underbrush many times faster than a man.

Here it is timely to set forth rather fully the special conditions under which our expedition was operating. Most collectors had simply to get near a gorilla, shoot it anywhere in the body one or more times, skin it and take the skin and head back to camp. We had permits to secure two gorillas in east Africa; and we considered that no mistakes or rejects were allowable. Our two gorillas must be large adults and they must be shot only in the head. If shot through the body, many blood vessels would be cut and it would be very difficult to preserve the huge body evenly; the preservative fluid injected would reach only certain regions; other regions would not be



Photograph by H. C. Raven

SOMETHING TO KEEP AWAY FROM.

NETTLES (*Urticaria*) ON THE GORILLA TRAIL.

Photograph by H. C. Raven

SWAMP NEAR TSCHIBINDA.

ACROSS THIS SWAMP THE GORILLAS RETREATED SWIFTLY, LEAVING US HOPELESSLY OUTDISTANCED IN THE LATE AFTERNOON.

reached by it and would "go bad" perhaps on the ship going home. Moreover, in killing a gorilla one had, if possible, to avoid killing it at some inaccessible locality where it would be difficult or impossible to bring out a four- or five-hundred-pound mass on the backs of porters. Consequently in both east and west Africa Raven had to miss very many opportunities of merely "shooting a gorilla." He could indeed have made a large collection of gorilla skins and skulls in the time it took him to secure our full total of five specimens (two in the Belgian Congo, three in west Africa) under these hampering conditions.

As Raven had already had far more field experience in Africa than the rest of us and was moreover by preference a solitary hunter, operating only with black trackers, he alone did the hunting and shooting of the gorillas; but it was open to the rest of us to take a native or two and go out to find gorillas for ourselves in the hope of securing motion pictures.

Some of Raven's experiences in hunting gorillas in this region have been vividly told by him in an article in *Natural History* (May–June, 1931), from which the following description is quoted:

The present range of the mountain gorilla is in the highlands of the eastern Belgian Congo and the Kivu volcanoes. Our camp in this country was west of the southern end of Lake Kivu, at an altitude of 7,000 feet, on the slope and facing eastward over the cultivated country toward the lake. On a clear day we could see the hazy outline of the mountains on the far side, and on one occasion I could even see the volcanoes north of the lake. The forest began just behind our tents. This was mountain forest with rather low trees interspersed among a mass of succulent vegetation which was from six to fifteen feet high. Many of

the trees on the highest slopes were covered with moss.

As soon as our camp was established I made daily excursions in the forest, accompanied by two or three natives whom I obtained in the neighborhood. We found traces of gorillas, elephants, harnessed antelope, duikers, wild pigs, and buffalo, but we did not get close to any of the gorillas. The natives were not good hunters, and when we came upon signs indicating where gorillas had been feeding or walking, they were unable to say whether these signs were fresh or a few days old. Finally I managed to get some Batwa pygmies, professional hunters, to help me. It was delightful to go into the forest with these little people who understood the forest, whose home it was.

One morning when I had started out with a couple of Bantu natives, two pygmies joined us and told us that gorillas had been feeding in a valley not far away. I accompanied them down the steep slope for nearly half a mile and up another ridge. The pygmies traveled much more quickly than the Bantu hunters I had had, and soon I was tired out. At the end of the steep climb of a half hour I had to sit down and catch my breath. Then we went on, up and down steep slopes, through the thickest kind of tangled vegetation, and finally came upon the trail of some gorillas, which we followed for perhaps a mile. Then we saw vegetation that had been trampled, stalks of wild celery that had been broken off and pulled through the teeth of the animals so that all the green bark and leaves were stripped off and eaten, while the perfectly white inner part, looking like a peeled willow switch, was dropped on the ground. After an examination of these switches, the pygmies turned to me and declared that gorillas were near, that this food had been eaten only a few moments before.

We proceeded very cautiously, one pygmy going before me with a peculiar combination sickle and hatchet (mgoosu), quietly cutting away the vegetation so that we could follow. We had gone along a densely covered ridge for perhaps one hundred yards when we heard a slight movement of the vegetation. On the advice of the natives I took the rifle from the boy behind me and went ahead more cautiously than ever. Suddenly and without the slightest warning there was the most terrific combination of screech and roar, stamping of feet and thrashing of underbrush, as a gorilla rushed at us. The vegetation here except for a few trees was dense as could be, and from ten to fifteen feet high. In order to get through we had been crouching down, often going on our hands and knees. I was crouching when the gorilla began to rush, but in order to raise the rifle in his direction I had to back up against a thick mass of vines and weeds. The gorilla came like a cyclone until he was perhaps thirty or forty feet from us, when he suddenly stopped and was silent.

Photograph by H. C. Raven

PYGMY HUNTERS.

CHILIGONOA STANDS AT THE RIGHT, WHILE NYUMBA IS NEXT TO HIM.

The vegetation was so thick we could not see more than ten feet in that particular direction. We hesitated a moment, then I motioned the hunter before me to part the vines quietly and go forward. I followed, holding the rifle ready to fire. We came to the spot where the gorilla had stopped, but he was not there. He had turned about, retraced his steps a short distance, then taken a new course, and disappeared, all without making a sound. By this time he was probably some distance away. We followed the trail as quickly as we could, first up along the ridge, then down the side of a steep ravine, until I was dripping with perspiration.

As suddenly as before, the gorilla rushed at us and stopped, and precisely as we had done the first time, we followed. On the brow of a ridge we came upon a very fine bed where this or another gorilla had slept the night before. It was about three feet in diameter, and was made of bamboo leaves. I would have stopped to photograph this had we not been in such hot pursuit.

That gorilla made seven similar rushes before he went down a very steep hill, across a small stream and over another hill nearly one thousand feet high. The pygmies then gave up and turned back, saying: "There is no use following him; he has gone too far."

Another day we had hunted up and down hill for hours without seeing any fresh signs of gorilla, though we saw many old ones. At this time I had only pygmies with me, no Bantus. Like the fine hunting people they are, the pygmies are ever on the alert to procure any food available in the forest. On this particular day, one of them who was ahead scouting called back to us, and when we came up to him, he was standing still, looking up at the trunk of a tree about three feet in diameter. He told us he had seen bees go into a crack in the trunk and that there must be plenty of honey inside.

Well, the hunt was over for that day. The pygmies simply could not think of leaving all that honey there, and promptly went about collecting it. First they cut a sapling about four inches at the base; this they stood against the big tree, and then tied it with vines to the tree at intervals of several feet all the way up. While two or three were doing this, another had found and shredded some bark, which he lighted and waved about, making it smoke profusely. One man climbed to the very top of the sapling, waving the smoking bark, and reached his hand into the crack of the tree. He reported that there was honey there, but said he would have to make the hole larger in order to get his arm in. Another native carried up a little hatchet of his own making. With this he hewed at the crack until it was big enough to admit his arm.

By now, of course, bees were buzzing about his head and all around the tree, sometimes getting tangled in his kinky hair, so that he would have to stop working at the hive momentarily. We could see him bring out pieces of comb; the honey would drip down from his precarious perch while he chewed up the comb, spitting out the wax afterward. All the natives below were keeping up an incessant jabber, begging him to throw down the honey, but he would only say "Wait," as he licked his fingers and arm.

It was not long, however, before he began to pass down pieces of comb to the native who had climbed up just below him. Then those on the ground would beg this man, "Pass down some honey," and like the one above, he would reply "Wait!" Finally there were five or six pygmies clinging to the sapling and eating honey. When they had removed all the honey from the tree and we had all had our fill, the remainder was bundled up in leaves and we returned home; for after procuring the honey their enthusiasm for gorillas was gone.

Another day we had come upon the trail of a band of gorillas among some bamboos perhaps three miles from camp. We followed them for a long way until about 11:00 A.M. when we came upon the place where they had slept the night before. In an area twenty yards across there were nine beds, all on the ground on the steep hillside. It was easy to see how they had made their nests. The gorilla simply sits down among the dense foliage and with his long arms grabs a small sapling, pulls it down, twists it under him, sits on it, and reaches for another. If it breaks off, he takes the piece, arranges it around him and continues to pull off, and twist around until he has made a nice nest or bed. Sometimes they undoubtedly walk a few yards to get the material for a bed, but as a rule, where the foliage is so dense, they simply sit down and pull the material about them.

After carefully examining the sleeping-quarters we followed on, dividing into three groups as the gorillas seemed to have done, but we had much difficulty in trailing them because elephants had been tramping all about.

One of the pygmies on my right suddenly spoke to the others, who darted forward as fast as they could go. I could hear the other pygmies, then the noise of an animal, then blows. When I reached them I found they had killed a wild pig that had been caught in a snare. After they had tied it up, two old men were left behind to carry it while we continued our hunt. Not more than a half mile farther on we could look across a little valley. On the opposite side a boy had seen the vegetation move and he was sure gorillas were there. We watched closely and, finally, with the binoculars

Photograph by E. T. Engle

LUNCHEON ON THE TRAIL NEAR MT. NAKALONGI.

RAVEN STANDS IN THE CENTER, WHILE THE PYGMY HUNTERS SQUAT AROUND THE FIRE.

Photograph by H. C. Raven

GORILLA BEDS.

GORILLAS USUALLY FEED UNTIL DUSK, THEN SITTING DOWN AMONG THE FOLIAGE THEY USE THEIR LONG ARMS TO PULL DOWN LEAVES AND VINES, ON WHICH THEY REST IN APPARENT COMFORT. IN RAINY WEATHER THEY TAKE ADVANTAGE OF SHELTER AFFORDED BY FALLEN TREES AND DENSE FOLIAGE.

I could see a black arm reaching up to pull down the bushes. We stole quietly down into the valley and then worked around so that we could come up-wind toward the feeding gorillas. We had first sighted these gorillas about noon, but it was 2:00 P.M. when we approached them. There were several, perhaps nine, as we had seen nine nests. They were quiet except for an occasional short grunt, indicating, I believe, that they were feeding quietly or perhaps telling their whereabouts to others of the group. They had moved slightly from where we first saw them and now were in low forest, the trees of which were fairly buried by lianas, many of whose stems were six inches in diameter. Underneath was a tangle of stems of thick undergrowth, so that in some places we could not be sure, on account of the irregularity of the terrain, whether we were looking at the ground or into the trees. There were many fresh signs of gorillas and we could see the place where one had sat down to eat. We felt the earth and found it warm; the animal had been there just a few seconds before. We were now right among them, and could hear them in three directions. Then I caught a glimpse of one in a tree, perhaps thirty feet from the ground.

I had with me a 30–30-calibre Savage rifle and also a 22-caliber rifle, the cartridges of which were less than an inch in length. In these tiny 22-caliber bullets I had drilled a hole and put in a small dose of highly poisonous potassium cyanide. If this actively poisonous substance could be introduced into the gorilla, whether his hand or head or body, he would drop dead within a few seconds. However, it was a question whether the heat generated in the bullet would not disintegrate the cyanide so that its poisonous action would be lost.

Using the 22-caliber rifle, I fired at the arm of the gorilla in the tree. Immediately there was a bark, screams, and wild commotion through the vegetation, as the gorillas rushed away. We rushed after them and found a few drops of blood from the one that had been hit. This one we carefully stalked. None charged or rushed at us; they were apparently thoroughly frightened. We followed cautiously

until about 5:00 P.M., when we had to give it up in order to find our way to a trail before dark.

It was evident that the cyanide had not worked on the animal, but the question arose as to whether it probably would die before morning. Early next morning, therefore, we took up the trail again and followed all day. The gorillas had gone on feeding, including the one that had been hit. He was apparently none the worse for the wound, which of course was not bleeding on the second day. Probably that wound did not do as much harm as a bite from one of his friends, received in play, or a stab from a broken branch.

After several days of hunting near camp I decided to go farther up into the mountains to reach a place called Nakalongi. This was an all-day walk. I had with me several pygmies and a personal boy as well as a few porters. It rained most of the afternoon and was raining when we stopped at a little beehive-like hut high on the side of the mountain in a bean patch. To the west were hills covered with grass but in every other direction the hills and gullies were covered with dense forest. The natives immediately set to work to build for me a little dome-shaped hut of the coarse grass that grew round about. Its diameter was about the same as the length of my bed-roll but it shed the rain. Cold gray mist filled the valleys and often shut off everything more than twenty yards away. I ate my dinner at night crouched beside the fire with all the natives that could crowd in, then went into my own hut to sleep.

As soon as it was dawn we were up and shortly afterward set out to hunt. Most of the men remained in camp but four pygmies accompanied me. We first climbed up the mountain through a mass of cold, wet bracken, then de-

Photograph by H. C. Raven

WILD HONEY.

THE PYGMIES OF THE KIVU CLIMB A BIG TREE BY LASHING A SAPLING TO IT. THEY ARE HERE SHOWN PASSING DOWN HONEYCOMB FROM A HIVE WITHIN THE HOLLOW TRUNK.

Photograph by H. C. Raven

THE DEAD MONARCH ON HIS BIER.

scended into a ravine through virgin forest so dark that it seemed like twilight. After about a half-hour of walking, very difficult on account of the steep and slippery ground, we came upon gorilla tracks and saw the remains of chewed-up stems. The forest had been so cold and wet that it was impossible to tell whether the material had been chewed that morning or the day before. We followed on, however, and soon found tracks that had not been dripped on from the branches above. Farther on we saw signs that we knew were not more than a half-hour old. About an hour from the time we began to follow the trail we were passing diagonally down a steep slope toward a tiny stream. Across the ravine sixty or seventy yards away, we saw the vegetation move and we caught glimpses of an animal between the branches. Then we must have been seen or heard, for there was a sudden short bark. We followed across the stream and up the steep slope, climbing with difficulty where the gorillas could pass with ease. It was much more difficult for me, with shoes, than for the bare-footed, strong-toed, unclad natives, and still easier for gorillas with powerful bodies, short legs, and long arms. Man's long legs are suited to the erect posture and not well adapted for going through underbrush, where he must be doubled up much of the time.

We were now getting close to the gorillas; we knew there was not a large troop, perhaps only three or four, but there was one big male among them, as we knew from the tremendous power in the bark he had given. The pygmies were nervous, saying that he would rush at us. We had gone less than three hundred yards from the stream and were still going through dense underbrush when suddenly the rush materialized with a terrific roar and shriek. The pygmy that was crouched down ahead of me, cutting the vegetation, sprang back and raised his spear, while I stood ready to fire. But like the other gorilla, this one stopped short, and did come into sight, although there seemed to be more ferocity in this animal. We continued on the trail and in a short time he rushed at us again. This time he was directly at our left, not ahead of us. Here the forest was a little more open and we could see perhaps ten or fifteen yards, but still he did not come within sight though we could see the vegetation move.

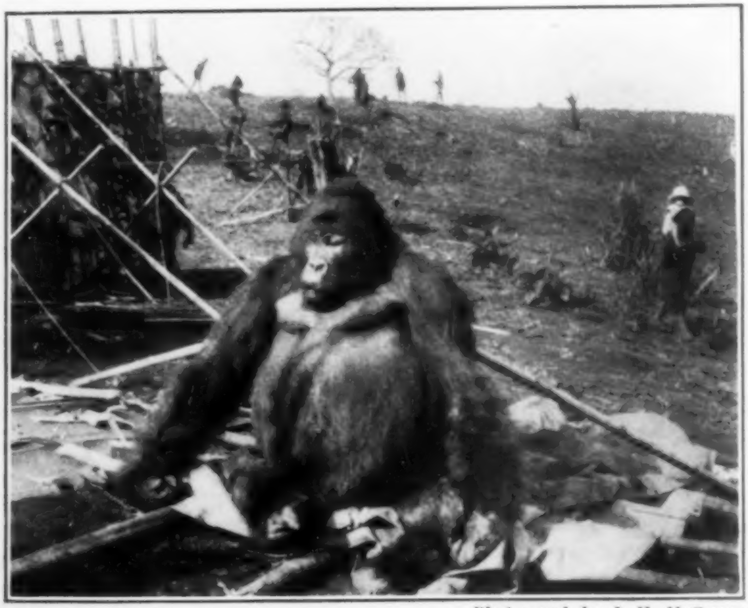
Finally we started up the slope. One pygmy went ahead of me, holding in one hand his spear and in the other his little sickle. He passed beneath a fallen tree and I had just stooped

under this tree when the gorilla, closer than any time before, gave a terrific roar. I was afraid I was going to be caught under the tree but I managed to step forward and raise myself. As I did so I could see the great bulk of the gorilla above me and coming straight at me. I fired at his head as I might have fired at a bird on the wing. The impact of the bullet knocked him down and I wheeled to the pygmies, yelling at them not to throw their spears. I feared they would spoil my specimen. But they in turn shouted to me, "Shoot! shoot!" The gorilla was not dead. When I looked around he was standing up like a man; it was plain to see that he was stunned. I fired again and he dropped lifeless exactly fifteen feet away.

This animal was the most magnificent I had ever seen, weighing 460 pounds. He was black and silver-gray, a powerful, courageous creature, determined to drive off intruders from his domain. Upon closer examination I found this giant primate as clean as could be. The long, shaggy hair on his head and arms was as if it had been combed only five minutes before. The silver-gray hair on his back was short and rather stiff.

Then came the time for quick action, for the specimen must be embalmed within a few hours. It must be got on to the trail, the trail must be widened from a foot to ten feet up and down steep mountains for about twelve miles. I sent a note to my companions in camp, telling them that I had secured the gorilla and asking them to send more porters. I sent another boy to call up the natives that had come into the mountains with me. While I examined the fallen gorilla, some of the pygmies were starting to make a bed or framework of saplings on which to carry him. These saplings were of strong, hard wood and very heavy. Three long saplings were placed about eighteen inches apart and numerous cross-pieces then lashed to them with vines. The gorilla was lashed on the top of this litter.

By about three in the afternoon we had the gorilla out on the trail where I could embalm him. We then wrapped him in a large canvas tarpaulin and made him more secure on the litter. I refused to leave him at night for fear a leopard or other animal might attempt to eat the flesh, so the natives made a little grass hut for me right there on the trail. More porters arrived the following morning and I detailed several to go ahead to widen the trail. The gorilla and litter together weighed more than six hundred pounds. However, the natives started off chanting and went along for some distance at fairly good speed. After getting my paraphernalia packed in the loads I followed and caught up with them as they were trying to get up a very steep incline, where there was scarcely any foothold among the rocks and mud. I had told them that we must reach camp by nightfall, but it was soon evident that this would be impossible. As a matter of fact, it took two and a half days, during which there



Photograph by J. H. McGregor

THE NAKALONGI GORILLA IN CAMP.

Photograph by H. C. Raven

WHERE THE GORILLAS CAMPED FOR THE NIGHT.
RAVEN IS SITTING BESIDE ONE OF THE GORILLA BEDS.

were several severe electric storms that the natives claimed were caused by my having killed the "king of the mountain forests." They said the same thing happened when someone killed a very large elephant. At night we simply had to sleep in the forest in whatever shelter we could make of leaves and branches, but it was always wet and cold.

Many of the natives ran away as soon as it got dark and I never saw them again, but as this was the main trail between Lake Kivu and Nakalongi, there were natives passing along at intervals, and some of these were persuaded to help carry the gorilla. When we arrived at camp we continued the work of preservation and all took part in the making of photographs.

Meanwhile the rest of us in camp had kept in touch with Raven by means of messengers, so that when the gorilla arrived all was in readiness for its reception. We heard the tumult and chanting in the distance and soon the porters struggled up the slope to our camp, while the chants grew louder and fiercer. We could see the gigantic man-ape in his white funeral wrappings, his immense abdomen swelling high above his mighty black chest. Finally as the bier came opposite our main tent the toiling pallbearers raised the chant to a climax. With a mighty heave they raised the bier above their heads and then, taking a step backward, they let it down to the ground. No wonder the whole neighborhood was excited and we most of all. After that Raven consented to stay in camp for a couple of days before beginning the quest for Number 2.

The taking of the second gorilla was in this wise. Late one afternoon (August 23rd) I was standing on top of the hill behind Mr. Vierstraet's house, strug-

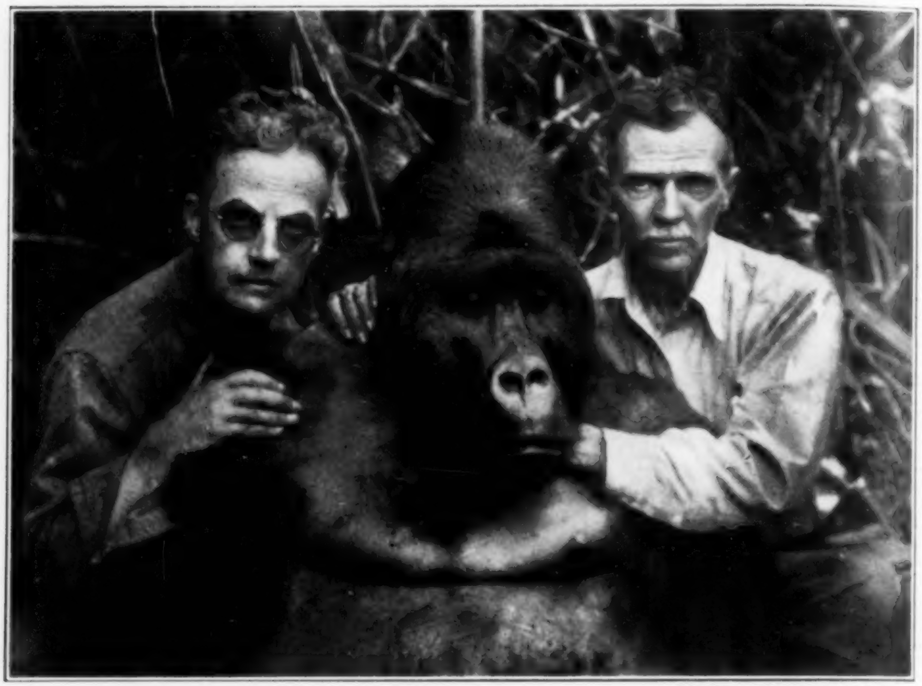
gling to make a pencil sketch of the immeasurable panorama of mountains and lake, when from the forest a little way behind me came the sharp bark of a gorilla. There could be no mistake that it was a gorilla, so I hurried down the hill and across the field to the camp to tell Raven. But meanwhile a native had come to tell him that gorillas were near by and he had left camp immediately. In a few minutes he sent back one of the two natives to guide McGregor and myself. About three minutes' walk from our camp brought us to a corner of the forest where the gorillas were preparing to make their camp. Raven was already there and had caught glimpses of several of them. He was not intending to kill any that night, as it was already too dark in the forest to get a good shot and he had reason to believe they would stay there all night.

With the utmost care, for fear of disturbing them, we peeked over the nearby bushes and saw the branches waving where one of the big ones was making his bed by bending down stems and sitting on them. Then we could see one or two black bodies with long arms very deliberately climbing a tree. We watched with the greatest eagerness until it grew dark and then sneaked back to camp. Late that night Raven, believing that the gorillas would be sound asleep and wishing to determine their exact positions, took a couple of natives, his gun and a flashlight and with great skill crept up quite close to them, heard their stomachs rumbling in their sleep and got away without disturbing them. Early next morning he left with two natives, promising to send after us at the earliest possible moment, his object being to kill a big female first and then, if possible, let McGregor get cinema views of the rest.

Unfortunately for Engle, he had generously walked down to Bukavu on the

Photograph by J. H. McGregor

THE PROSTRATE GIANT OF TSCHIBINDA.



Photograph by H. C. Raven

PRIMATES ALL.

day before with a band of porters to secure supplies for us, so that to our great regret he missed this intensely interesting occasion. McGregor and I stood on the top of the rise to the left of our camp; through our field-glasses we could distinctly see the branches move as the gorillas stirred about. We heard a shot, a sharp bark, then silence. A few moments later the native came toward us and beckoned and we started with the cinema camera. We sneaked quickly up a rear pathway and found Raven crouching under a great low-branching tree, with several gorilla beds under and near this tree and many smaller ones in the branches above us. Less than forty feet away several gorillas were hidden in the bush and we in turn were screened by a curtain of vines and bushes, with a couple of irregular openings for peepholes. From about 8:30 to 11:30 that morning we crouched in that spot, moving hardly at all and only with the greatest caution to avoid cracking a twig or rustling a leaf. McGregor crouched in front, holding up the cinema ready to start it in an instant. Raven crouched behind him with the gun, I a little to one side and two natives behind me. On the whole the two or three gorillas left there were strangely quiet. As we watched we could hear and see one of them beating its breast and making the strange sounds that one of our natives thought were made by slapping the hand against the thigh. At times we could see a large one, probably a female, leaning back on the bushes and now and again beating its breast. Once a big face peered through, looking straight toward McGregor, but before he could start the cinema it was withdrawn.

As time passed it seemed strange that the gorillas did not slink off into the thicket, as they were so adept in doing,

without making a sound. After a long time Raven whispered to the two natives and they went away on long detours to the right and left. They slunk off as quietly as the gorillas themselves, each one after a time coming back to whisper his report. Then Raven quietly gave the word for us to move forward. Less than thirty-five feet in front of us (the distance being measured later) we found the dead body of a great gorilla, lying face downward, resting on his folded arms and knees. The other big one, who had been waiting all morning for its mate or relative to wake up and go ahead, had now vanished.

Raven then told us that early that morning a very large male had appeared momentarily but he had not shot it, as he had already secured a large male and was now in search of a big female. Behind the male followed a broad face, which he took to be that of a large female and he had taken a quick shot at the face, his object being to shoot the animal through the head. There had been a loud bark, followed by the flurry of fleeing gorillas, then complete silence, and he thought that somehow he had missed the animal. But there the gorilla lay dead before us.

McGregor and I were intensely elated, but Raven was deeply disappointed and dejected, for two reasons: first, our second and last mountain gorilla was a male like No. 1, not a female as he had believed on account of its having been with a still larger male. Secondly, the single shot had narrowly missed the face and, the animal being on all fours, the bullet had passed obliquely downward through the neck and chest, thus probably tearing the great blood vessels upon which Raven was depending to carry preservative to all parts of the body.

However, there was very much to be

Photograph by H. C. Raven

HEAD OF *GORILLA BERINGEI.*

done and done quickly. First we raised up the dead giant into a sitting position, pushing him against the stout bushes where he had died. How clean and beautiful to us was the velvety black skin of his great face and how grave and calm the expression of his large, deep-set brown eyes! Although it was indeed a pity to kill so noble a living monument of past ages, we had not murdered him wantonly and for sport. This gorilla was destined to be, though unconscious of it, a missionary of science; for no one except those blinded by prejudice and ignorance could look at his titanic Jovian head and his mighty arms and hands without realizing that the creature partook of the nature of man, a fact which our natives were intelligent enough to realize.

Such were our thoughts as we made numerous cinema pictures of our precious gorilla. But time was passing all too rapidly and it was necessary to transport the animal back to camp where it could be injected with preservatives. It happened awkwardly enough that at this time we had had to let most of our first lot of porters go home and the second lot had not yet arrived. So we sent an SOS to our good friend Mr. Vierstraet, asking him for a gang of his farm laborers and then went back to camp for a hurried lunch.

By the time we returned Mr. Vierstraet's men were already cutting a broad path leading down the hill from the spot where the gorilla lay to the corner of the field at the left of our camp. In about half an hour also a number of saplings had been cut down, trimmed and lashed together to make a bier, upon which the huge body was rolled. Then with a mighty heave thirty or more men got their shoulders under the projecting poles and the funeral procession started. It was surprising to see how enormous the dead giant looked on his bier, as the crowd struggled up the slight rise leading to camp, while McGregor got cinema

Photograph by H. C. Raven

ENGLE PUTS UP HIS PRESERVES.

Photograph by H. C. Raven

HANDS OF GORILLA AND MAN.

THE GORILLA'S FINGERS ARE WEBBED. NOTWITHSTANDING THE SHORTNESS OF THE GORILLA'S THUMB, IT CAN BE BROUGHT INTO CONTACT WITH THE OTHER DIGITS WHEN THE HAND IS FLEXED.

records of them. What a pity there was no way to record the weird droning chant of the pall-bearers as they came up the hill, or their final shout as they lifted the great burden from their shoulders to their upraised arms and then let it down in front of the camp. Meanwhile every white person in the vicinity and crowds of blacks swarmed around the dead gorilla.

One of the natives did something which surprised me considerably. He was evidently trying to convey to another man the idea that the gorilla was very big. He took a stick and held it against his own upper arm, holding his thumb and forefinger at the right distance from the top. Then he placed the stick in position along the front of the gorilla's upper arm to show the great difference in favor of the gorilla. Here, I thought, is the beginning of physical anthropology, and for that matter, here is where physical anthropology has too often stopped, with a mere measurement of differences.

The next business was the preservation of this very difficult subject. As Raven had feared, the great vessels were cut by the bullet and he had a tedious and dif-

ficult job to locate the cut ends, tie in the cannula and make separate injections through the carotid and femoral arteries.

In the course of these operations it was deemed advisable to empty the digestive tract, partly because the enormous mass of material in it would under the present circumstances be difficult to sterilize and prevent from fermenting. As this was done, pail after pail was filled first with the contents of the stomach and then with that of the lower sections of the tract. The material from the stomach contained an immense amount of succulent green material, which appeared to remain largely undigested even in the lower end of the tract. No parasites were found until the lower bowel was reached, when small round worms, that Dr. Engle thought might be *Ankylostoma,* and tapeworms, similar in appearance to the human types, appeared in great numbers. A series of these parasites was preserved by Dr. Engle for future study. No external parasites were found. The vermiform appendix (which the anthropoids share with man) was present. In general, one saw that here was a digestive system of practically human type, but with the abdomen expanded to hold a huge quantity of vegetation. Thus the swelling abdomen, the huge quantities of ingested vegetable tissue, the cross-crested molar teeth and stem-cutting tusks afforded certain analogies with hoofed herbivores, such as tapirs, mastodons and wild boars, but the deeper anatomical features were far more like those of man.

Engle and I took many detailed finger and palm prints of this gorilla, which had loops and whorls of surprisingly human appearance. I should like to have a professional palmist read the lines in this gorilla's palm. McGregor made plaster molds of the face and entire bust of the animal, as well as molds of the hands and feet. The latter proved to be much larger than those of the female secured by Akeley and are most imposing objects.

After the killing of the second gorilla I redoubled my efforts to discover fresh gorilla traces in the immediate neighborhood of the camp, while Raven and Engle searched in distant localities, as

Photograph by J. H. McGregor

SOLE OF THE LEFT HIND FOOT OF GORILLA.

IN WALKING THE GREAT TOE SPREADS OUT FROM THE OTHERS BUT, ESPECIALLY IN THE RELAXED CONDITION, IT CAN BE DRAWN IN NEAR TO DIGITS 2–4. THE TOES ARE WEBBED FARTHER OUT TOWARD THE ENDS THAN THEY ARE IN MAN.

Photograph by E. T. Engle

IN CAMP ON MT. KAHUSI.

THE BAMBOO STICKS HAVE BEEN FASHIONED INTO A RUDE TABLE WITH WIND-BREAK. TWO OF THE PYGMY HUNTERS ARE SMOKING NATIVE PIPES.

Photograph by H. C. Raven

CLOSING DAYS AT TSCHIBINDA.

Photograph by H. C. Raven

LOOKING NORTH FROM THE NAKALONGI TRAIL.

we were now keen to get some cinema records before leaving this region. On several days I took a few Batwa, promising them large rewards if I could even catch sight of a gorilla. They harangued me earnestly each time, but all I could make out was "No gorillas . . . elephants." But Raven told them to go with me and they did sŏ. We went up hill and down dale but never came across a fresh gorilla sign, although several weeks before they had been quite numerous. The only souvenir of a gorilla that we saw on the entire strenuous climb was in a charming little open field of small green bushes high up on the mountain, with gigantic dark trees all around in the background. At one spot a gorilla had sat down on a clump of bushes to bask in the sun and perhaps to doze a little. Then he had risen, idly sheared off a tall twig and drawing it between his great canine teeth had stripped it entirely of its fragrant outer layer and tossed it away for us to find. *"Ngagi"* (gorilla), said the Batwa, and my hopes were revived, even if this were an old trace. And it was some compensation to see the little old gnome of a Batwa tell me the story in pantomime.

Meanwhile Raven and Engle had made a long excursion to Mt. Kahusi in the hope of finding gorillas in the bamboo forests and getting a chance to make cinemas of them. Although they found no trace of gorillas they saw many interesting things, such as native iron-smiths fashioning their iron spearheads. Fairly fresh elephant tracks were abundant.

Just before leaving Tschibinda I told all this to Mr. Van der Stok, general manager of the plantations and experimental farm.

"Why, of course you didn't find many fresh gorilla traces at that time," he said, in substance. "Every year in September when the elephants come to Tschibinda, the gorillas move out and are gone until after the end of December, when they return."

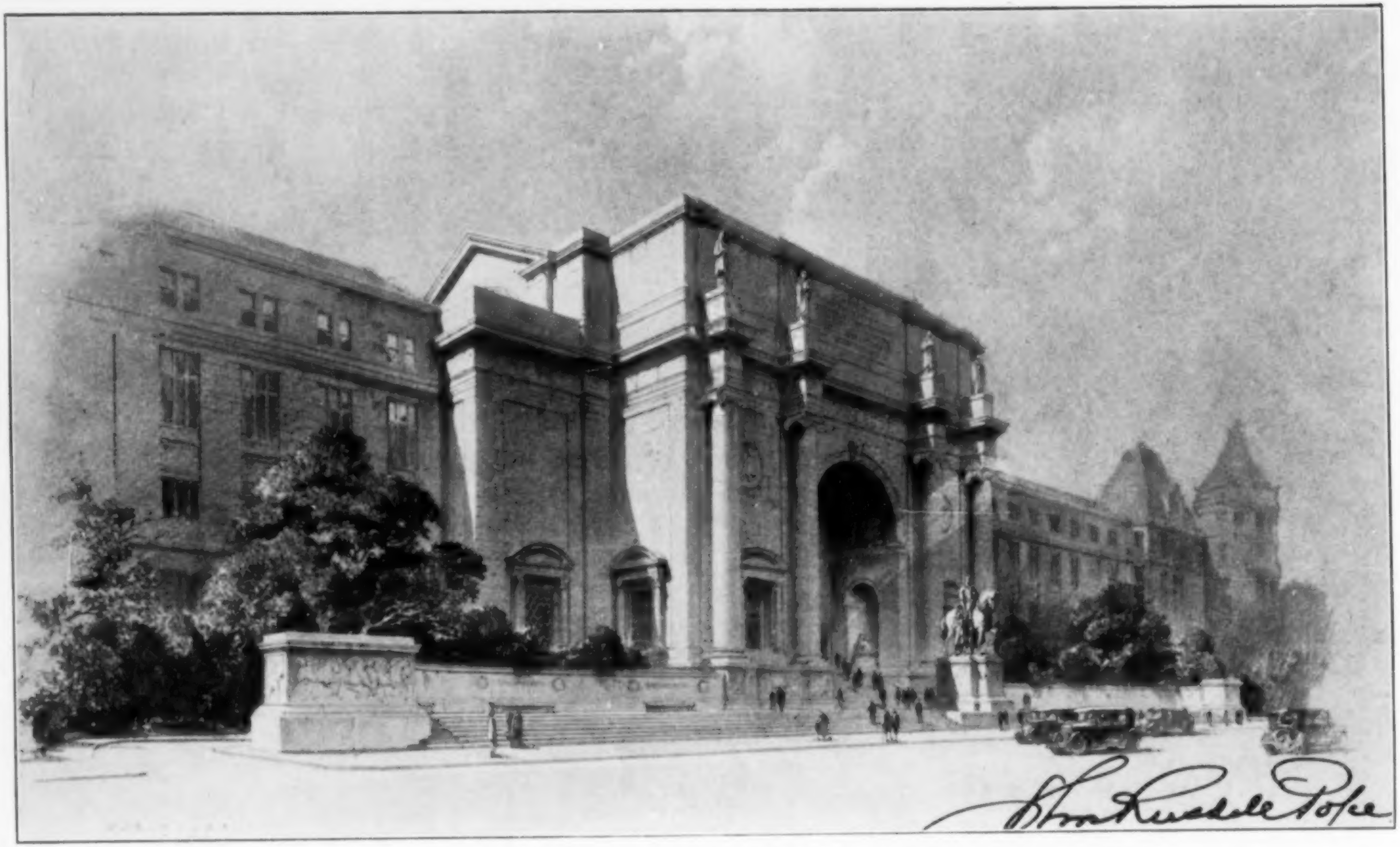
Then I realized that the Batwa had been imploring me not to waste my time and theirs. But my colleagues are sceptical about all this, urging that the forest is a very big place, that after all I was seldom more than a mile or two from

camp, and that I might have passed quite close to gorillas without their presence being betrayed.

Our stay at Tschibinda was prolonged far beyond our expectations, chiefly because we did not dare to ship our second gorilla until we had done everything we could to prevent it from "going bad" on the long journey home. The cutting of the great vessels above the heart had made it very difficult to preserve the entire body properly. At last, however, the body had been injected in many places and it seemed to be resisting sufficiently well the forces of decay. Raven therefore wrapped it up like a mummy, covered its bandages with melted paraffin and after considerable correspondence obtained a camion, in which he took the body all the way down to Uvira at the head of Lake Tanganyika, whence it was shipped by rail and boat to Dar-es-Salaam and eventually forwarded via Marseille to New York. But in spite of all our efforts the long journey through the high temperatures proved very hard on this specimen, which arrived in New York in poor condition. Fortunately, the other four of the five gorillas obtained by Raven in East and West Africa all arrived in excellent condition and have since been studied by several specialists.

On account of the delay at Tschibinda we were forced to give up our plan of proceeding to the upper end of Lake Kivu and of visiting the Parc National Albert which lies to the north of this lake. There we had intended to try for motion-pictures of the living gorillas in the Parc. But it was necessary that at least three of us return to New York before February first, and judging from our experience of unexpected delays it would take a couple of months to make the long journey across Africa either to the French Congo or some other part of the range of the lowland gorilla of West Africa.

(A further article in the series entitled "In Quest of Gorillas" will be printed next month.)



THE NEW YORK STATE ROOSEVELT MEMORIAL

The architect's drawing is reproduced because the recent completion of the building makes a photograph unsatisfactory. The equestrian statue of Roosevelt is not yet in place.

THE PROGRESS OF SCIENCE

THE NEW YORK STATE ROOSEVELT MEMORIAL

ON Sunday, January 19, the board of trustees of the New York State Roosevelt Memorial held the dedicatory exercises in that building.

President Roosevelt delivered the principal address, "A Tribute from the Nation." Participating with him in the exercises were Governor Herbert H. Lehman and Mayor Fiorello La Guardia, who spoke on the relation of the memorial and its effect on state and city, respectively. These speakers were followed by A. Perry Osborn, who outlined the "Guiding Principles for Memorial Administration," and by Colonel Theodore Roosevelt, Jr., with an address of "Appreciation." Dr. James R. Garfield, the closing speaker, spoke on "Roosevelt the Man"; and the exercises closed with a benediction by Dr. Charles W. Flint, a trustee and chancellor of Syracuse University.

After the death on January 6, 1919, of Theodore Roosevelt, the late Professor Henry Fairfield Osborn, in cooperation with leading New York newspapers, advocated the erection of a memorial to Roosevelt that would be educational in character. In 1920 Governor Smith appointed a commission to examine the question of the proposed memorial, and later this temporary commission rendered a report. A second commission was appointed in 1924 by Governor Smith, who stated that he would like to see a plan for a memorial "which would for all time stand as a visible expression of the recognition of the services of one who had been most active in the welfare and development of our State and Nation."

Several years of intensive study by the commission resulted in the development of the plan which has now become a realization. The factors decided upon as essential to the plan were: First, to interpret the character of Roosevelt as a naturalist and citizen; second, that the form of the memorial must primarily be an educational institution, as no other form would adequately memorialize the broad humanitarian intelligence that Roosevelt possessed, and that every facility should be incorporated which would give students an opportunity to study nature, know its phases from all angles, and be led to emulate the extraordinary knowledge that Roosevelt attained; third, that the memorial should suggest a lofty standard of idealism through lines inspired by models chosen from the golden age of architecture, that there should be evolved a design which would symbolize the spirit of Roosevelt and by its impressiveness infuse those ideals for which Roosevelt strove and many of which he gained.

As soon as the form of the memorial was decided, efforts were made to secure the necessary funds for its construction, and in 1924 the legislature enacted a law providing \$250,000 with which to defray necessary expenses, and subsequently provided the sum of \$3,500,000 for the work. After a competition in which many prominent architects participated, John Russell Pope was selected as the architect.

The program of competition stated that "the nature lover should be stressed by monumental architecture, sculpture and mural paintings. The design should symbolize the scientific, educational, outdoor and exploration aspects of Theodore Roosevelt's life rather than the political or literary." In Mr. Pope's plan these features are blended most harmoniously. A monumental structure, graceful in every line and inspired by the stately designs of the old Roman archi-

MEMORIAL HALL

tecture, it conveys to the beholder an impression of spaciousness and enduring strength.

The façade is modeled on the triumphal arches of ancient Rome. The entrance arch rises to a height of sixty feet above the base, and is flanked on either side by huge granite columns supporting heroic figures of Lewis, Clark, Audubon and Boone, outstanding characters in early American history.

These prominent features, together with its deep recesses, shadows and reflections, and its mammoth bronze screened window, most successfully unite the exterior with the interior.

From the practical and educational standpoint the building is splendidly equipped with classrooms, exhibition rooms, a lecture hall that will seat six hundred people, a hall for the display of the resources of New York State and a room devoted to Rooseveltiana. At the right of the entrance vestibule are located the administration offices or Trustees' Room, while at the left is a group of superbly finished panelled butternut wood interiors, forming a suite of rooms to be known as the Statesmen's Rooms. A cafeteria and lounge are located in the basement, and from that floor direct access can be had to the platform of the Eighth Avenue Subway.

The façade of the building is executed in pink granite. On the parapet wall surrounding the terrace are carved inscriptions indicative of the fullness of Roosevelt's life as follows: Ranchman, Scholar, Explorer, Scientist, Conservationist, Naturalist, Statesman, Author, Historian, Humanitarian, Soldier and Patriot. Upon the pedestals supporting the exterior columns and the pedestals flanking both ends of the terrace, which is 350 feet in length, Edward Field Sanford, Jr., the sculptor, has carved in bas-relief the figures of animals native to America and Africa. A vehicular drive-

way adjoins this terrace, passing about the rear and leading to the first floor entrance.

In the center of the terrace, immediately in front of the great entrance arch, upon a polished granite pedestal, will be an equestrian statue of Roosevelt with two accompanying figures on foot, one an American Indian and the other a native African, representing his gun bearers and suggestive of Roosevelt's interest in the original peoples of these widely separated countries. This group will rise to a height of thirty feet above the sidewalk. It is the work of James E. Fraser, the well-known sculptor, who designed and executed the four statues that surmount the great columns on the main façade.

Passing through this entrance, one steps into the Memorial Hall itself, a conception of grandeur and dignity in harmony with the spirit of Roosevelt's lofty ideals and fearless character. This hall, exclusive of recesses, is 67 feet wide by 120 feet in length. The floor is richly patterned in marble mosaic, the walls, to a height of nine feet, being of St. Florient cream marble surmounted by mellowed limestone extending to an elaborate Corinthian cornice and culminated by an octagonal barrel vault, reaching to a height of 100 feet above the floor. At either end of this vaulted ceiling the walls are penetrated by large circular-headed windows which furnish the hall with ample daylight. In order to avoid the deteriorating effects of direct daylight on the murals, the architect has skilfully designed recesses in the walls at three sides of the room. These three recesses with a fourth containing the entrance arch have each two Roman Corinthian columns forty-eight feet high supporting the entablature. The shafts are executed in a red antique marble.

In the three great recesses have been

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A SECTION OF THE AFRICAN MURAL

IN THE WEST RECESS OF MEMORIAL HALL. IT IS THE WORK OF WILLIAM ANDREW MACKAY, WHOSE MURALS IN THE HALL COVER AN AREA OF OVER 5,000 SQUARE FEET.

placed mural paintings which form a most important part of the general decorative scheme and in themselves successfully portray the varied activities of Theodore Roosevelt. The artist, William A. Mackay, has given the north recess over to the subject "The Panama Canal," the south recess to "The Treaty of Portsmouth" and the west recess to "African Exploration." In these murals, covering a total area of 5,230 feet, the artist has selected and skilfully presented the outstanding achievements rendered by Roosevelt both to our country and to the world.

In the spaces within the memorial quotations from Roosevelt's writings and sayings have been arranged under four headings as follows: Nature, Manhood, Youth, The State.

For more than sixteen years the late Professor Henry Fairfield Osborn had given his time, energy and thought to produce a structure which he felt would best memorialize Theodore Roosevelt. With these ideas constantly before him he developed a planned structure of such grandeur and beauty, combined with utilitarian purposes, that it is believed it stands without a peer. Within its walls one immediately responds to the thoughts which Roosevelt felt most applicable to mankind.

The trustees of the American Museum of Natural History, who will later control the operation and maintenance of the memorial, have pledged themselves, in their acceptance of the memorial, to carry out the educational purposes laid down by their late President Osborn for their guidance; to regard the sacredness of the memorial; to keep faith with the people of the state; and to be true to the ideals of Theodore Roosevelt.

GEORGE N. PINDAR,
Secretary of the Board of Trustees

LEWIS BUCKLEY STILLWELL, EDISON MEDALIST FOR 1936

THE Edison Medal, the highest honor conferred by the American Institute of Electrical Engineers, is awarded for meritorious achievement in electrical science, electrical engineering or the electrical arts. Within the broad scope thus indicated, the medal has been conferred upon eminent scientists such as Bell and Millikan, inventors such as Thomson and Pupin, educators such as Ryan and Kennelly, engineers such as Westinghouse and Sprague, and others equally preeminent in the field of applied electrical science.

Lewis Buckley Stillwell, the recipient in 1936, is distinctively of the engineering group, the well-recognized functions of which are economic planning, technical design and execution. The distinction of Stillwell's career lies in the novelty and magnitude of the projects with which he has been entrusted, the extent to which they have involved far vision of specific as well as general economics and the welfare and convenience of large groups of the public, and their ultimate conspicuous success. He is fitted for the large and varied problems and many such have come to him.

Indicative of his conspicuous talent is the fact that at thirty years of age, as general engineer for the Westinghouse Company, he was in general charge of the planning and installation of the electrical equipment for the first development of Niagara Falls power and its transmission to a distance. This was an enterprise which was not only record-breaking and revolutionary in many of its aspects, but which immediately attained success, and, in its use of alternating current, has served as a pattern for the enormous subsequent expansion in this and other countries of long distance electric transmission.

Of equal magnitude and equally noteworthy in their advances over existing methods were his plans for the installation of the first electrical equipment for the Manhattan Elevated Railways, and

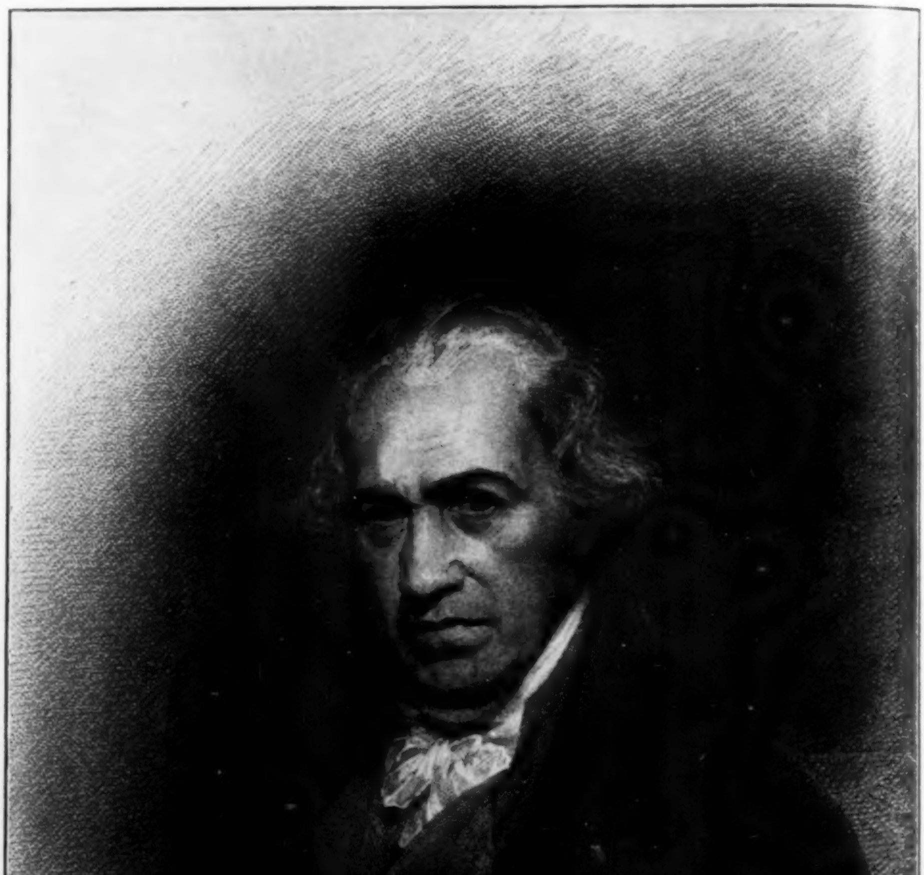
World Wide

PRESENTATION OF THE EDISON MEDAL

TO LEWIS BUCKLEY STILLWELL (LEFT) BY EDWARD B. MEYER, PRESIDENT OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

particularly that for the first subway system in New York City. He has been intimately identified with many of the projects involving mass transportation in and near New York, all involving new methods and enlarged facilities, and all marked by conspicuous success. Transmission and transportation, in large terms, have been his specialties, and many important projects in these fields have come to him.

Although such a professional record would of itself have merited the Edison Medal, Mr. Stillwell's contribution to the profession has extended much further in the high standard of professional conduct which not only have guided his own career, but which he has enunciated on many occasions and otherwise supported to the building up of the high code of professional conduct prescribed by the American Institute of Electrical Engineers. He has a deep sense of the opportunities for public service open to the engineer, and the consequent responsibility upon him to give of his best and in accordance with the highest ethical and professional principles. He frequently has found time to give to the profession and to the public many results of his careful study and analysis, and to take active part in movements looking to a more unified position and activity of the engineering profession in public affairs. Many of his published papers have dealt with major national problems, as for example, "The Relation of Hydro-electric Power to the Conservation of the Nation's Resources." Several other such papers constitute excellent examples of the type of service which a competent engineer with a high



JAMES WATT

sense of public duty may render to a government sincerely in search of guidance. A further paper on "The Status of the Engineer" marked the beginning of a long-continued effort to bring together in some coordinate form the common interests of the various branches of the engineering profession, and which culminated in the establishment of the American Engineering Council, the important channel for the exchange of information and service between the entire engineering profession and the public, governmental and other agencies.

J. B. WHITEHEAD,
Dean of the Faculty of Engineering
THE JOHNS HOPKINS UNIVERSITY

THE WATT BICENTENARY CELEBRATION IN THE UNITED STATES

THE two hundredth anniversary of the birth of James Watt, whose improvements of the steam engine led to the train of events which constituted the industrial revolution, was celebrated on January 19, 20 and 21 with a three-day program arranged under the joint auspices of Lehigh University, the Franklin Institute of the State of Pennsylvania, the American Society of Mechanical Engineers and the North American Branch of the Newcomen Society of England.

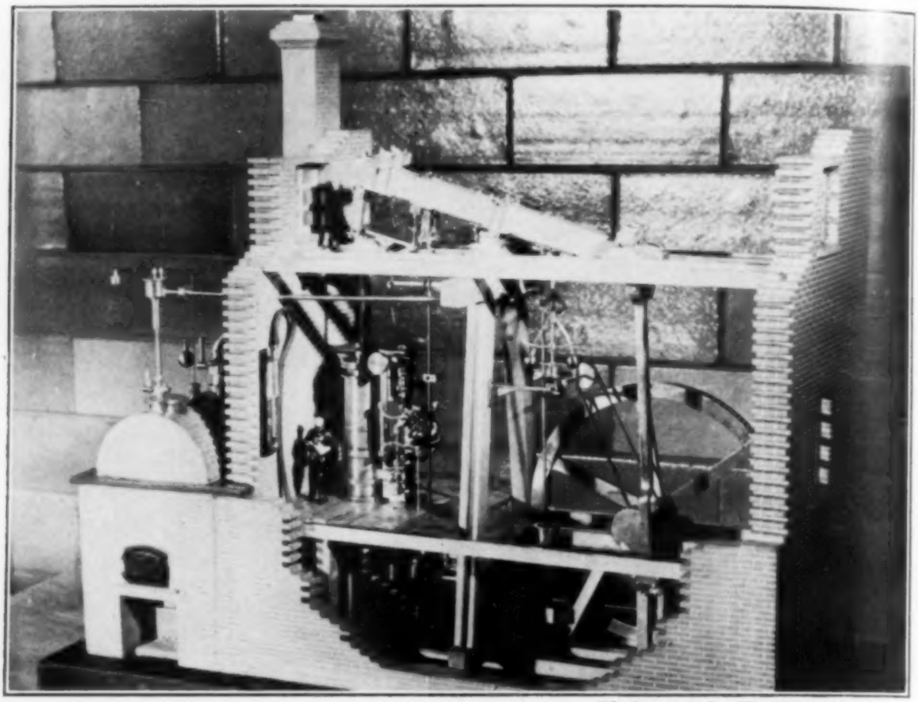
In the development of this celebration the committee issued an early invitation to the engineering societies, to scientific and technical bodies, to historical associations, to local engineering clubs and societies and to the engineering colleges, inviting them to participate in the celebration by sending delegates to the meetings at Lehigh University and at the Franklin Institute, or by holding their own simultaneous meetings.

The response to this invitation was wide-spread, particularly on the part of the engineering colleges in the United States and Canada, where more or less generally, some class assembly, convocation or student society meeting was dedicated to the celebration, by appropriate lectures bearing on James Watt and the industrial development which followed his pioneering achievements.

The celebration opened on Sunday, January 19, with an international broadcast from the Science Museum, South Kensington, London, England. Colonel Alexander Elliott Davidson, aid-de-camp to the late King George and president of the Institution of Mechanical Engineers, reviewed Watt's accomplishments and extended greetings to the participating bodies in the United States. "Old Puff Puff," the Watt engine built in 1799, rattled through her paces under the direction of Mr. H. W. Dickinson, director of the museum. The Franklin Institute followed immediately with a broadcast bearing greetings from the sponsoring bodies and with a display of the models in their justly famous Hall of Prime Movers.

The next day, January 20, the celebration was continued at Lehigh University with a three-session program. At eleven o'clock, Robert L. Sackett, dean of the School of Engineering of the Pennsylvania State College, presided over a panel discussion on "The College Graduate in Industry." Represented in the discussion were the personnel directors of prominent industries and members of engineering faculties from neighboring colleges.

At three o'clock, Arthur M. Greene, Jr., dean of the School of Engineering of Princeton University, presided over a "Colloquium on James Watt," where papers dealing with the life and work of Watt, his association with Matthew Boulton and with the significance of that notable partnership, were presented respectively, by George A. Orrok, Professor Joseph W. Roe and Dean Dexter S. Kimball. The addresses were followed by a demonstration of Newcomen and Watt engine models built at the university.



Photograph by W. Mansfield White

MODEL OF THE WATT STEAM ENGINE AT LEHIGH UNIVERSITY

The evening session was opened by the induction of Clement C. Williams, president of Lehigh University, into the North American Branch of the Newcomen Society of England. Addresses were made by William L. Batt, president of the American Society of Mechanical Engineers, who spoke on "Watt—Symbol of the Industrial Age," and by William C. Dickerman, president of the American Locomotive Company, whose subject was "Some Problems of a College President."

The celebration was concluded on January 21, with two sessions held in Philadelphia. During the afternoon, the Franklin Institute was host to the participating bodies. Following an exhibition and demonstration of Newcomen and Watt engine models in the Hall of Prime Movers, the Newcomen Society conducted a meeting presided over by Charles Penrose, vice-president for North America of the Newcomen Society of England. "Greetings of Great Britain" were extended by Sir Gerald Campbell, K.C.M.G., British consul general, New York, and "Greetings of Scotland—Land of James Watt's Birth," by Andrew Baxter, Jr., president of Saint David's Society of the State of New York. Mr. Penrose himself addressed the group on the subject, "Monday, January 19, 1736, in North America," depicting Washington as a lad of four and Franklin as a man of thirty at that time.

From a historical point of view, Dr. Thomas Jefferson Wertenbaker, Edwards professor of American history at Princeton University, spoke on "James Watt: Inventor and Pioneer." Addresses bringing personal experiences in the development of the steam engine for the electric industry and in the development of the steam locomotive were given by

James Alward Seymour and Samuel M. Vauclain, respectively.

The final session of the three-day celebration was a formal dinner held at the Bellevue-Stratford Hotel in Philadelphia, under the auspices of the Franklin Institute, President Nathan Hayward presiding, Conrad N. Lauer, toastmaster. A "Eulogy on James Watt," prepared by H. W. Dickinson, of London, was read by Colonel C. E. Davies, secretary of the American Society of Mechanical Engineers. Julian P. Boyd, secretary of the Historical Society of Pennsylvania, addressed the gathering on "Civilization Since James Watt." "Steam in its Relation to Marine Engineering, the Electric Industry and to the Railroads" was discussed respectively by Rear-Admiral Harold G. Bowen, George A. Orrok and William C. Dickerman.

Papers presented at the Lehigh University program are printed in the February, 1936, issue of *Mechanical Engineering.* Those presented at the meeting of the Newcomen Society will be published in the proceedings of that body.

The Watt Bicentenary Committee follows: Fred V. Larkin, director of mechanical engineering, Lehigh University, *chairman;* Henry Butler Allen, director of the Franklin Institute; Clarence E. Davies, secretary of the American Society of Mechanical Engineers; Charles Penrose, vice-president for North America of the Newcomen Society of England.

F. V. LARKIN,
Chairman

THE MEASUREMENT OF COSMIC RAY INTENSITY

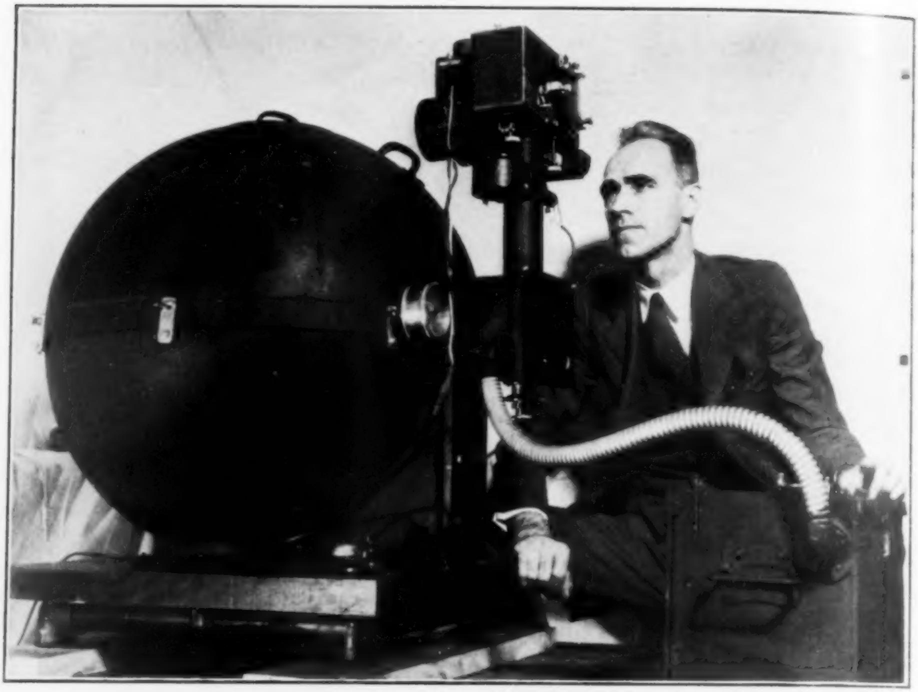
VARIATIONS in cosmic ray intensity, a subject of wide scientific interest, are being studied at the Massachusetts Institute of Technology this winter with one of the seven new cosmic ray intensity meters which are to be used in a world-wide investigation of cosmic radiation under the auspices of the Carnegie Institution of Washington.

These new instruments, each of which weighs more than a ton, were designed and built at the University of Chicago under the direction of Dr. Arthur H. Compton, with Dr. A. W. Simon, also of the University of Chicago, and Professor Ralph D. Bennett, of the department of electrical engineering at the institute.

The purpose of these extremely sensitive meters is to measure the variations from normal in cosmic ray intensity and to discover, if possible, the source of the rays by correlation of these variations with such manifestations as sidereal time, sun-spot cycles, terrestrial and solar magnetic storms and the rotation of the galaxy. The meters will also be used to study the nature and origin of the bursts of energy released in the form of thousands of cosmic ray particles traveling downward together at enormous velocities; the total energy in each burst surpasses by thousands of times that of any other known atomic cataclysm.

In designing these instruments the problem was to produce mechanical means of making continuous records of the behavior of cosmic rays for long periods without attention. Each of the new meters employs a small motor to drive a moving strip of photographic film in a camera which records the measurements over a period of months.

Measurements of cosmic ray intensity are made possible in this instrument by their effect on very pure argon gas, which is confined in a 14-inch steel bomb at a pressure of 750 pounds to the square inch. To avoid interference from other forms of radiation, such as those from radioactive materials in the earth and air, the argon gas bomb is buried in the center of a large steel sphere containing 2,500 pounds of lead shot, which acts as a shield against undesirable radiation, but which is easily penetrated by the cosmic rays.



ONE OF THE COSMIC RAY INTENSITY METERS

THE COMPARTMENT AT THE LOWER RIGHT CONTAINS BATTERIES, WHICH WILL OPERATE THE METER FOR A YEAR, AND THE CONTROL SWITCHBOARD AND STANDARDIZING METERS. PROFESSOR RALPH D. BENNETT, WHO ASSISTED IN ITS DESIGN, IS SHOWN WITH THE APPARATUS.

The cosmic ray meter at the Massachusetts Institute is already in operation in a laboratory in the department of electrical engineering under the supervision of Professor Bennett. After being tested under various conditions, the instrument will be taken next summer to Mount Evans, Colorado, where at an elevation of 14,265 feet above sea-level it will be operated as one of the instruments in the world-wide chain of stations. Professor Bennett, Gordon S. Brown and Henry A. Rahmel took the first model of the meter to the top of Mount Evans for tests last year. In the face of snowy gales, violent electrical storms and freezing temperatures they carried on investigtaions for several weeks that aided in the final design of the meters.

One meter is now in operation at the field station of the Carnegie Institution at Cheltenham, Maryland. Another is on its way to Peru, where it will be installed at the magnetic observatory at Huancayo. Another is to be sent to the interior of the Mexican highlands, and one will be taken to the Danish observatory in the northern Greenland ice fields. Still another will be stationed in New Zealand, and the seventh at the University of Chicago.

J. J. R.